A Virtualised Routing Protocol for Improving Network Lifetime in Cluster Based Sensor Networks

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List of Abbreviations

APTEEN	Adaptive Periodic TEEN
BCDCP	Base-Station Controlled Dynamic Clustering Protocol
CEED	Centralised Energy Efficient Distance
CGC	Centralised Genetic-Based Clustering
CH	Cluster Head
CM	Cluster Member
CN	Centroid Node
DEC	Double-phase Cluster-head Election Clustering Protocol
DL-LEACH	Double Cluster Based Energy Efficient Routing Protocol
EAGR	Energy Aware Greedy Routing
EEE-LEACH	Energy Efficient Extended LEACH
EE-LEACH	Energy-Efficient LEACH
EE-LEACH-C	Energy Efficient LEACH-C
E-LEACH	Extended LEACH
EP-LEACH	Energy potential LEACH
ETSI	European Telecommunications Standards Institute
FND	First Dead Node
GAF	Geographic Adaptive Fidelity
GEAR	Geographical and Energy-Aware Routing Protocol
GPS	Geographical Position System
HEED	Hybrid Energy-Efficient Distributed clustering
HND	Half Nodes Die
ID	Identification
IP	Internet Protocol

LEACH	Low-Energy Adaptive Clustering Hierarchy
LEACH-B	LEACH-Balanced
LEACH-C	Centralized LEACH
LEACH-CC	LEACH Central Constrained
LEACH-F	Fixed- LEACH
LEACH-SC	LEACH-Selective Cluster
LND	Last Nodes Die
MAC	Media Access Control
MANET	Mobile ad hoc Network
MATLAB	Matrix Laboratory
MEMS	Micro-Electro-Mechanical Systems
MWE	Multiple Winner Algorithm
N- LEACH	Narrative-LEACH
NFV	Network Function Virtualisation
PDU	Protocol Data Unit
PEGASIS	Power-Efficient Gathering in Sensor Information Systems
QoS	Quality of Service
SAR	Sequential Assignment Routing
S-LEACH	Solar LEACH
SN	Sensor Node
SPEED	Stateless Protocol for Real-Time Communication in Sensor Networks
SPIN	Sensor Protocol for Information via Negotiation
SWE	Single Winner Algorithm
ToP	Type Of Packet
VCR	Virtualised Clustering Routing

Abstract

In Wireless Sensor Networks (WSN), enhancing network lifetime is one of the critical challenges that should be considered during the network design. Sensor nodes exhaust their power in various activities such as sensing, processing and communication that represents the most energy-consuming and therefore should be managed to improve the network lifetime.

The clustering has a significant task on network lifetime because sensor nodes consume a considerable amount of energy during the transmission and receiving in order to perform the clustering function stages. Clustering is the process of grouping sensor nodes into groups that are administered by a node known as a cluster head (CH). The main stages of this function are the setup stage, responsible for the cluster formation and cluster head selection, and the steady state stage (data transmission). By managing and reducing the number and amounts of communications as well as computation during these stages efficiently, will affect the nodes' energy consumption and enhance network lifetime.

The aim of this thesis is to improve the network lifetime by virtualising the clustering function to be implemented into high-volume central server on the cloud as well as using efficient approaches in cluster formation (based on k-means algorithm) and in cluster head selection (based on current nodes energy level and their distance to sink). These processes will result in a reduction in the number and amount of communication messages and the computational needs for each node during clusters formation and cluster head selection, thus improving the network's lifetime. Hence, a new virtualised clustering routing protocol based on Network Function Virtualisation (NFV) has been proposed. NFV is a new network virtualisation approach that helps to minimise the design requirements in terms of hardware, power and space. The new approach uses a mathematical model which has been developed in this work to estimate the energy consumed during the operation of the proposed protocol.

The analysis of the proposed protocol that is based on the Matlab2016a simulator showed that by utilizing the approach of the cloud computing and enables a NFV server to manage and control the network as well as use efficient approaches in cluster head selection and cluster formation, will lead to improve the network lifetime. The results regarding First Node Dead (FND) showed that the new protocol the existing clustering protocols and the network lifetime improved to double.

Chapter One

Introduction

1.1 Introduction

Following the developments in the fields of Micro-Electro-Mechanical Systems (MEMS) technology and wireless networks, tiny sensor nodes with limited power and computing resources have been designed for the monitoring and controlling of physical environments (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002a) (Potdar, Sharif, & Chang, 2009).

Wireless Sensor Networks (WSN) are a special kind of ad-hoc networks that gained considerable attention for its uses in various applications such as health and environment monitoring. This network composed of a large number of tiny, low cost and limited battery-powered sensor nodes collaborate with each other to perform various tasks. Therefore, because of the limited nodes' energy resources, maximising network lifetime is one of the critical challenges that should be considered during the network design. Sensor nodes exhaust their power in various activities such as sensing, processing and communication that represents the most energy-consuming and therefore should be managed to improve the network lifetime.(Akyildiz et al., 2002a) (Alkhatib & Baicher, 2012) (Lewis, Moncrief-O'Donnell, & Chair, 2006).

Depending on the application and the environment, the WSN contains various types of sensor such as seismic, thermal, visual, infrared, and acoustic. Each one of these is used to sense and monitor a certain ambient condition such as temperature, humidity, vehicular movement, lighting condition, pressure, soil makeup, and noise levels. Owing to the wide separation of

WSN, they are used in different applications such as military, business, environmental, health, traffic monitoring and home monitoring (Tan, 2006) (Malfa, 2010).

The characteristics of WSN are different from other wireless networks because they are application-dependant. Many requirements should be considered when designing WSN; such as energy consumption, localisation, topology control, deployment, computation process, data aggregation, scalability, cost, hardware limitation and security (Tan, 2006) (Malfa, 2010).

One of the most important issues in the design of this network is how to prolong the network lifetime. The network lifetime is based on the energy level of the nodes which consume their energy in different activities, such as communication, sensing, data processing, and collision, (Patil & Patil, 2013).

Routing poses difficult challenges in the design of a sensor network because of its characteristics that distinguish it from other types of wireless network such as Mobile ad hoc Network (MANET) (Cecílio, Anjos, Costa, & Furtado) (Mundada, 2012). With regards to energy consumption, the routing process consumes a considerable amount of energy in the communication between sensor nodes to perform different functions such as clustering.

Clustering is grouping sensor nodes into clusters that are administered by a node known as a cluster head (CH). The cluster head receives the data from the cluster members, aggregates and forwards it to the sink via a single-hop or multi-hop communications. The main stages of this function are the setup stage, responsible for the cluster formation and cluster head selection, and the steady state stage (data transmission). The sensor nodes consume a considerable amount of energy during the setup stage because of a large number of communication messages during the cluster formation and cluster head selection processes. Accordingly, reducing the number of communications as well as computation should be one of the objectives in the design of energy-efficient clustering routing protocols.

In this chapter, the research problems, question, aim, objectives and the strategy are defined. This is preceded by a brief description of Network Function Virtualisation (NFV) as it is an important component of the research

1-2 Network Function Virtualisation (NFV)

The European Telecommunications Standards Institute (ETSI) industry group has founded NFV to reduce network complexity. The NFV is one of the cloud computing applications. Cloud computing and NFV have some similarities but are essentially different. The network function virtualisation technique opened the field towards unifying the networks and information technologies by hosting the network functions in the cloud (corporation, 2013). This technique could apply to any network function and can reduce space, energy, cost and dependency of hardware components (Wikibon, 2013).

The notion of this virtualisation technique came from the need of the network providers to accelerate the deployment of any new network services to support their growth objectives; this should reduce complexity and make network management faster and easier. The function virtualisation technique opened the field towards unifying the networks and information technologies (corporation, 2013; Taylor, CTO, & Networks, 2014). A simple concept of this technique is shown in Figure (1-1) (Wikibon, 2013) (ETSI, 2012) (Central, 2013; Pate, 2013).

This technique is the newest and one of the most important topics for the network vendors today. It introduces a new approach to networks' virtualisation that helps to reduce the hardware, power and space requirements of the design. It also simplifies the process of managing and deploying new network functions. The difference between this approach and the traditional network virtualisation is its attempt to virtualise particular network functions rather than the entire network (ETSI, 2013a; Taylor et al., 2014) (Yue, 2013) (Jain, 2013).

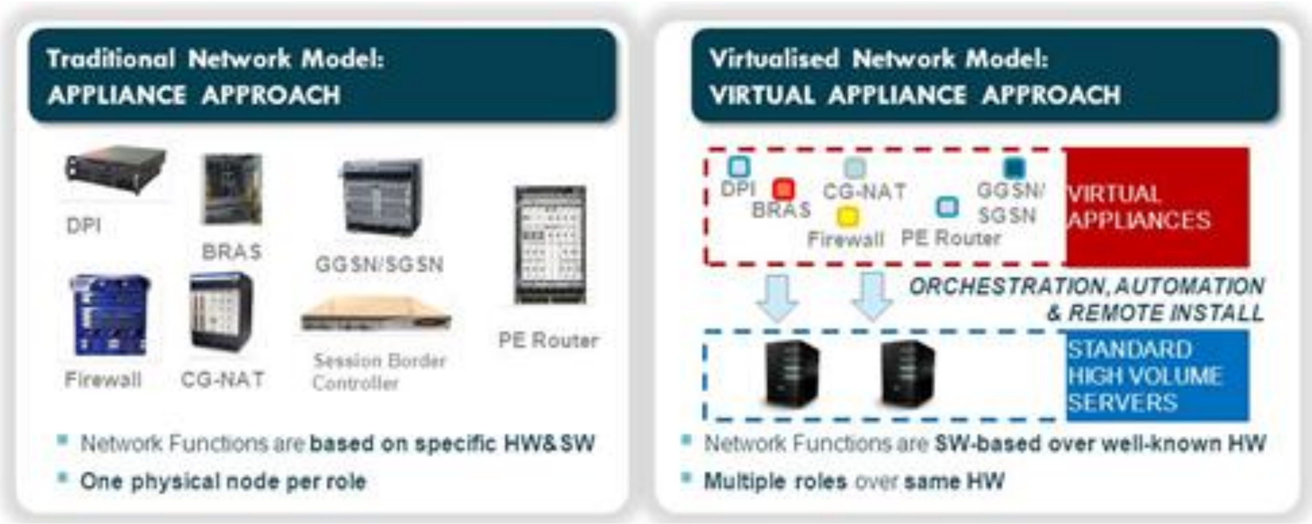


Figure (1-1) NFV Concept (http://slideplayer.com/slide/4680105/)

This technology has various advantages which can be summarised as follows: (ETSI, 2013b) (Radcom, 2013):

1. Reduces the dependency on specific hardware as well as minimising the purchase cost for new equipment. For instance, instead of adding new hardware to enable network encryption, software related to this function can be used.

2. Minimise the space and energy consumption for the network components.

3. Facilitation of the networks upgrade.

4. Allows network operators to share their resources with different services and customers.

1-3 Research Problem

The popularity of WSN has increased tremendously recently due to the growth in wireless networks technology. Prolonging the network lifetime has become a crucial challenge in the design of this network. The nodes' energy consumption is the main factor that determines the network lifetime. According to this, the improvement of the network lifetime is achieved by the reduction of the sensor nodes' energy consumption.

The nodes’ energy is consumed in different fields such as communication between the sensor nodes and the sink, sensing the environment, and processing the data. However, the most energy-consuming aspect is the communication. For example, the power to process thousands (approximately 3000) of instructions is equal to the power required to transmit a data of 1-bit size (Pottie & Kaiser, 2000) (Patil & Patil, 2013) (Ahmedy, Ngadi, Omar, & Chaudhry, 2011) (Ali & Roy, 2008) (Anastasi, Francesco, Conti, & Passarella, 2006).

In wireless sensor network (WSN), many functions affect the sensor nodes’ power level; the most important function is the routing. Hence managing the routing function will lead to reducing the energy consumption (Alkhatib & Baicher, 2012) (Ayyat, 2013) (Dekivadiya & Vadharia, 2012).

In general, routing is the process of transmitting the data from the source to the destination via the most efficient route; the routing has a significant and costly task in term of determining network lifetime in WSN.

The energy consumed in the routing process has been considered the highest due to various routing functions such as clustering, which relies on both Intra-communication (among sensor nodes) and inter communication (between sensor nodes and the sink). Therefore, the principal reduction of the energy consumption is achieved by minimising the Intra and inter communications (Akkaya & Younis, 2003).

The cluster head receives the data from the cluster members, aggregates and forwards it to the sink via a single-hop or multi-hop communications. The main stages of the clustering function are the setup stage (clusters formation and cluster head selection) and the steady state stage (data transmission). The setup stage is essential because it is responsible for the cluster formation and cluster head selection. In the setup stage, the sensor nodes consume a considerable amount of energy because of a large number of communication messages tramnsnitted during the clustering function (cluster formation and cluster head selection stages).

In clustering sensor networks, routing protocols can be classified based on the responsibilities of the clustering function into distributed (the nodes responsible for the clustering function) and centralised entral node, generally the sink is in charge of this function. The distributed clustering is location unaware, which may lead to a non-uniform distribution of cluster head selection and cluster formation. Moreover, the clustering function occurs internally among the nodes, and this leads to an increase in the number of communications among the nodes to perform this role.

However, centralised clustering protocols are location aware, and there is a controller node (generally by the base station/sink), which controls and manages the cluster head selection, clustering formation and the number of clusters in the network. The initialisation of this type happens when the nodes send their information to the sink. Although it is better to be centralised than distributed, but the transmitting process that occur at the beginning of each round in the centralised type will cause extra energy consumption and overheads at the start of each round.

For both, the main problem which cause an overhead is the number of communications among the nodes and the sink that are required to perform the clustering. Accordingly, reducing the number and amount of communications during the clustering function as well as the efficient approaches of cluster formation and cluster head selection will lead to enhance the network lifetime.

1-4 Research Question

As mentioned previously, Network Function Virtualisation is a new approach for virtualisation to reduce the complexity and operations of the networking system by moving the network function to be implemented in a central server.

Therefore, by using the principles of this new technique in WSN, the main question of the research is to move the cluster formation and cluster head selection to a central server in the cloud and enable this server to manage and control the network topology. This will help to enhance the network lifetime and organising the network to be more efficient in terms of energy. To verify this hypothesis, a new virtulised and central clustering based routing (VCR) protocol has been proposed.

1-5 Research Aim and Objectives

The aim of this research is to enhance the network lifetime in cluster based sensor networks by managing and controlling the clustering function by a central server. This will reduce the energy consumption that occurs during this function and enhance network lifetime as well as organise the network to be more efficient regarding energy consumption in addition to making the clustering function share with other networks

The key objectives, which are designed to achieve the aim of the research, are:

1- Conduct a literature review of WSN, energy-consuming domains, clustering based routing protocols and clustering functions in order to determine the source of energy consumption in the clustering function. The concept of NFV will also be studied to find how it can minimise the energy consumption problem in WSN.

2- Design a virtualised and centralised clustering routing (VCR) protocol based on NFV to control a network topology and implement the clustering function.
3- Develop mathematical models for measuring the amount of energy consumption for the proposed protocol.
4- Simulate the proposed protocol and analyse the results to find the improvement of the network lifetime based on the first node dead (FND) parameter as a performance measure.

1-6 Contributions of the Thesis

To overcome the reseasrch problem, this thesis intends to utilise the concept of Network Function Virtualisation and smart environment of the cloud computing in designing a central clustering routing protocol to control and manage the clustering function in the network as well as use efficient approaches in cluster head selection and cluster formation in order to achieve the research aim. Therefore, the main contributions for the proposed protocol are:

1- Using a central control on the network will reduce the number and amount of communications that requires during the clustering function in distributed protocols.
2- Minimise the transmissions of nodes' information, which occurs at the beginning of each cycle in centralised protocols, by using one transmission process at the initialisation step of the protocol.
3- The server will utilise the nodes' information to optimise the cluster head selection and cluster formation based on node's current energy level and distance to balance the power consumption and improve network lifetime.
4- Regarding cluster head reselection, the proposed protocol will consider a trigged condition in order to reselect the cluster head nodes. This condition will based on the

current energy level of the cluster head node and cluster members. This process will make cluster head reselection more monitoring more efficient.

1-7 Research Process

The steps of the research process have vital importance in identifying the research field, selecting the main problem, proposing and implementing the design as well as evaluating and validating the results. The main steps of the research process are as shown in Figure (1-2). This section provides full information on the process of this thesis.

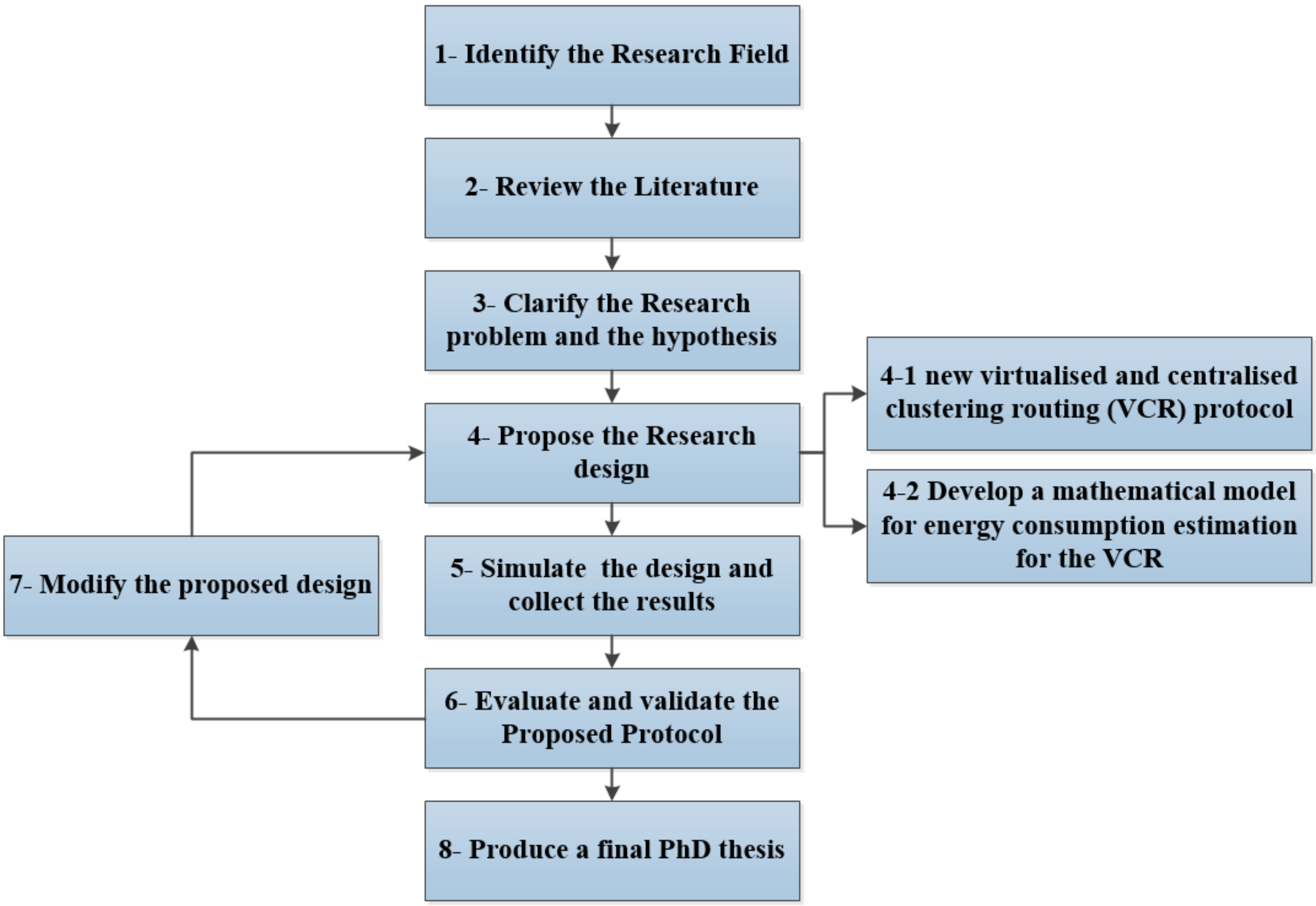


Figure (1-2) Research Process

1- Identify the Research Field

The first step of the process is to define the general field of this research. The research begins by carrying out a detailed analysis of the energy consumption problem in WSN, and the domains in which the sensor nodes consume energy, as well as which of these domains consume most energy, and how it should be modified to prolong the network lifetime

2- Review the Literature

This step provides the fundemantal knowledge about the research field. Much research has been reviewed to understand WSN functions, problems and applications, as well as different types of existing routing protocols, clustering protocols and algorithms had been reviewed in order to understand their fundamentals.

Furthermore, various mathematical models introduced for WSN were studied and reviewed to understand which domains should be taken into accounts during the design of the proposed mathematical model.

In addition to this, the NFV technique is a new network virtualised method to reduce the network complexity and power consumption. By taking all this into consideration, the main concept of this research study will be to exploit the NFV concept to minimise the energy consumption of the sensor nodes and improve network lifetime.

3- Clarify the Research Problem and the Question

The research problem that defined in the first step is broad in scope. In this step, the problem was clarified by narrows the scope of the study. As mentioned previously, the network lifetime and how to improve it is the main objectives in the design of any WSN’s clustering routing protocols. In addition to this, the power consumption in the clustering based protocol is reviewed in order to understand how the nodes consumes their power during the operation of the clsutering protocols and how it can be managed in order to improve the network lifetime.

4- Propose the Research Design

Based on the research problem and hypothesis, a research design has been proposed in order to achieve the aim and objectives. It is divided into two phases:

4-1 Propose a New Virtualised and Centralised Clustering based Routing Protocol for the Research Idea.

In this phase, a new virtualised and centralised clustering protocol is proposed. In the proposed protocol, the NFV server will be responsible for implementing the clustering function. Its operation based on two main steps: the neighbour discovery step, which will be used to send the sensor nodes' information to the server via the sink; and the clustering step, which will be implemented in the NFV server. The clustering step will be divided into the setup stage (the cluster formation and the cluster head selection) and steady state stage (data transmissions). Besides this, the k-means clustering algorithm is used to form the final clusters. The selection of the cluster head is based on a particular cost function, which is the combination of nodes distance to sink and its current energy level. The full details of the proposed protocol are discussed in chapter four.

4-2 Develop a Mathematical Model to Estimate the Amount of Energy Consumption for the Nodes

In order to monitor and manage the network during the protocol operation, a mathematical model is developed for the proposed protocol in this step. This model will be used by the server to estimate the amount of energy that will be consumed during the protocol process.

The model takes into consideration the fields that nodes consume their energy in, such as transmission, receiving, processing, sensing and status change.

5- Simulation of the Proposed Protocol.

This research is based on a simulation experimental and will therefore study and investigate the amount of energy consumption of the new protocol under different simulation parameters. In this step, the protocol is implemented and managed using the MATLAB R2016a simulator.

At the beginning of the simulation, the networks are fed with the necessary information such as the number of nodes, which are deployed randomly in the simulation environment (the sensing area with m*m size), the sink (base station) position. As soon as the nodes are deployed, they will be in stationary mode (fixed position).

The simulation is run under different topologies (randomly deployed) to investigate the network energy consumption. In addition to that, the number of nodes, the sink position and the sensing area are used as inputs. These are changed during the simulation to study their effects on the network and to find the best scenario for the network working in terms of minimum energy consumption.

The output of the system is the amount of power consumption with different parameters and finding the optimum number of clusters in terms of minimum power consumption. Furthermore, the network lifetime is measured based on the first node dead (FND) parameter. More details on FND are provides in chapter two.

6- Evaluate and Validate the Proposed Protocol

The results obtained from the simulation for the proposed protocol is collected and analysed in this step. Additionally, the protocol is validated based on different scenarios such as changed numbers of clusters and modified implementation parameters

The purpose of the proposed protocol evaluation to determine how far it achieves the aim of the research; this is done by comparing it with the traditional protocol (LEACH) and LEACH-C to find the difference between the results.

7- Modification to Improve the System.

During the simulation process, and if the amendment is necessary to improve the performance of the proposed protocol to minimise the energy consumption, this step is used to modify the protocol according to the evaluation of the results.

8- Produce a Final PhD Thesis.

The final step will involve making conclusions and recommendations, then present the complete PhD thesis.

1-7 Thesis Layout

The remainder of the thesis is organised as follows:

- Chapter 2 outlines the concept of WSN, its applications, sensor nodes architecture, WSN protocol stack, the energy problem in WSN as well as reviewing an explanation of the routing protocols, the design requirement of the routing protocol, and the classifications.

- The detailed information about the clustering technique is been explained in Chapter 3. Furthermore, the main classification for the available clustering protocol, which is distributed, and centralised clustering protocols had been introduced and various types of available protocols in both types has been described.
- The full description, assumptions and general steps for the proposed protocol are present in Chapter 4.
- The mathematical model and the final equations that will be used to measure the amount of energy consumption in the proposed protocol will be reviewed in chapter 5.
- Chapter 6 describes the simulation experiments of the research, which based on MATLAB simulator. It include the network parameters, topology and experiments. Furthermore, validating and evaluation results had been explained in this chapter
- Finally, Chapter 7 contains the main conclusions and future works.

Chapter Two

An Overview of Wireless Sensor Networks

2-1 Wireless Sensor Networks Background

Wireless Sensor Network (WSN) represents a class of network technology that is becoming increasingly popular today. WSNs are used to control and monitor the environment, and they contain thousands of sensors that communicate with each other to perform a particular task. Sensing is a technique that is used to collect information about a particular phenomenon or environment (Dargie & Poellabauer, 2010).

A sensor node forms the main unit of a WSN, which is used to measure changes in the environment such as vibration, temperature, pressure, humidity, noise and pollution. These sensor nodes are deployed randomly and in large density (Akyildiz et al., 2002a; Kalantary & Taghipour, 2014; Potdar et al., 2009).

The functions of these sensor nodes are transmitting the data, processing it and then communicating with each other to forward it to a central node, which is known as a base station or a sink via shared wireless channels. The sink either uses the data locally (sends it to users) or forwards it to other networks (such as the Internet) (Akyildiz et al., 2002a).

The main components of standard Wireless Sensor Network (WSN) are shown in Figure (2.1) and consist of:

1- Sensing area that can be considered as the field where the nodes will be deployed.
2- Sensor nodes, which represent the main part of the network and the heart of it and are responsible for sensing activities.

3- Sink or Base Station, which is the node responsible for control of the network and its high proprieties node with no limited resources. The sink acts as a gateway between the sensor nodes and the outer world. The sink needs to be in a good position because all the nodes communicate with it for network operation, and in general, the sink is assumed to be static and does not move in most of the available applications, except for some applications where the sink needs to move to collect data from the nodes.

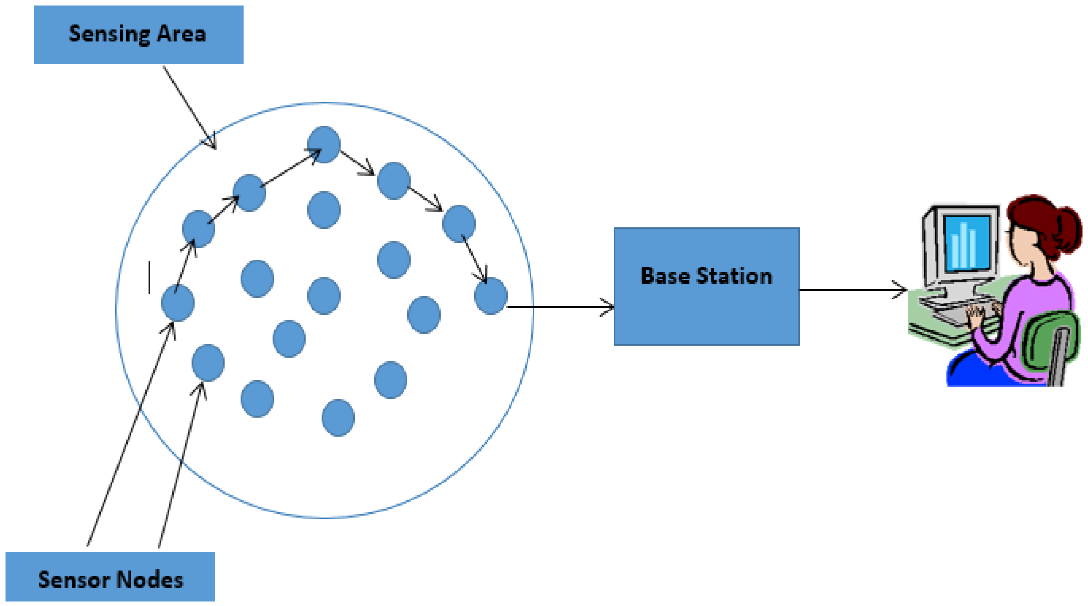


Figure (2-1) Simple Diagram of a WSN

At the beginning of designing this network, the communications were based on the concept of IEEE 802.11; later on, owing to the high power overload of this standard, it became clear that it was unsuitable for use with this network. Therefore, the new IEEE 802.15.4 standard, which is designed for short-range transmissions and low power sensor nodes, was utilised in the design of various commercial and academic sensor nodes (Dargie & Poellabauer, 2010).

Although this network is a type of ad hoc network, there are various reasons why the protocols designed for ad hoc cannot be used in the WSN. For instance, the number of sensor nodes in the WSN is huge, and this requires more scalability management. The sensor nodes are deployed once and in stationary mode, except for some applications that require mobility nodes. In ad hoc, however, the nodes are moving all the time. Moreover, the sensor nodes in the WSN have limited capabilities, such as in processing and energy constraints, and are also prone to failure. The overhead of the communication for network configuration is also too high, and in the WSN, the nodes use broadcasting during the operation while in the other ad-hoc network such as MANET, the nodes use the peer to peer communication. As a result, minimising energy consumption is the most significant problem in the design of the WSN (Gowrishankar, Basavaraju, Manjaiah, & Sarkar, 2008).

The design of WSN has special requirements such as power limitations, processing abilities, memory, fault tolerance, scalability, hardware constraints, transmission media, environment, deployment process, Quality of Service (QoS) and security (Akyildiz et al., 2002a; Potdar et al., 2009; Singh & Arora, 2013; Yick, Mukherjee, Ghosal, & Dipak, 2008).

2.2 Wireless Sensor Networks Characteristics

WSN characteristics are different from other types of wireless networks because it is an application dependent and changeable based on the network design; some of its features are (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002b; Potdar et al., 2009; Singh & Arora, 2013; Yick et al., 2008):

1. Energy Constraints: the network lifetime relies on the energy level of the nodes, so the power limitation of the nodes becomes the most important design issue in WSN. As the

nodes are battery powered, and the nodes are deployed in an unreachable environment, it is thus hard to replace the nodes' batteries or charge them with additional energy.

2. Limited resources: owing to the sensor nodes' small size and battery power, the processing ability is limited, as well as memory storage and lifetime.
3. Deployment: the deployment of sensor nodes in the network is application dependent and random. It has two types predetermine and post determine. In the predetermined type, the nodes deploy either dropping from a plane or are placed in the sensing field one by one by a human or robot. For the post deployment, there is a change in the topology by changing nodes' position and their abilities.
4. Fault tolerance and topology control: the fault of the sensor network should not affect the performance of the WSN function and should have the ability to change the topology map in case of any failure. This failure may be caused by various factors such as lack of power, physical damage and environment interference.
5. Application dependent: the characteristics are different from one application to another, so the protocols and algorithms for it are application specific.
6. Scalability: depending on application requirements, the number of sensor nodes may be increased or decreased. Therefore WSN performance should be continuous if new sensor nodes are added or removed.
7. Security: security is considered a major factor in WSN design to ensure application processing. Confidentiality, availability, integrity, authentication, authorization and others represent various security parameters. For instance, if the WSN is used in the military application, it requires a high level of authentication.
8. Reporting types: in WSN, data reporting categories are continuous, event based, query based or hybrid. In continuous types, the nodes send their data to the sink periodically and are based on the predetermined time slot; this is used in temperature sensing

applications. This type is considered to be the most energy-saving, as the nodes turn the radio to on only on their time slot. Event based types are commonly used in critical applications. The nodes operation here depends on a specific event to start working. For those applications that require data, when the nodes send their information based on a request from the sink, this type is known as query based data reporting. The data reporting this model has a higher priority than the previous two models. Finally, the combination of the three models is called the hybrid model.

9. Mobility: the nodes in this network may or may not have mobility properties. In general, most of the available designs of this network consider the nodes to have a fixed position. However, some applications require the nodes to be mobile and change their position based on specific conditions.
10. Production Cost: the main part of the WSN is the sensor node. Therefore, the cost of the single nodes has a significant impact on the design cost of the whole network.

To understand the fundamentals, architecture, design issues, connectivity schemes and problems of this type of network. Akyildiz et al. (2002a) introduced full studies and surveys in this field, providing the necessary background required for understanding this network type and its limitations. Furthermore, in order to understand the WSN architecture, a brief background on WSN architecture based in OSI model was introduced in (Alkhatib & Baicher, 2012).

In order to summarise the design limitaition and chalalnges in WSN, (Singh & Aloney, 2015) focusing on the general limitations and challenges of WSN that provide the necessary information regarding to the design of this network.

Some of the design issues that arise in the context of wireless sensor networks were reviewed by (Sahni & Xu, 2004), specifically, coverage, deployment, and routing algorithms. The problem of localisation had been introduced and addressed in different research fields;

various techniques of node localisation discovery were raised by Pal (2010) who discussed the future directions and challenges to improve localisation techniques in WSN.

2-3 Sensor Nodes Architecture

Sensor nodes are considered to be the main part of WSN, and they are used for sensing, processing and sending the data to the central nodes (sink). There are different types of sensor nodes such as thermal, seismic, infrared and acoustic that are used to sense different environment conditions such as vibration, temperature, pressure, noise, humidity, pollution, radiation, and the characteristics of the objects such as speed and the direction (Hu & Cao, 2010).

The sensor nodes contain various components as shown in Figure (2-2) and described in the following:

1- Sensing unit: this unit consists of sensors and analogue to digital converters. The sensor can be analogue or digital, and it is used to sense the environment and convert the data using ADC into a signal to be usable in the network.

2- Processing and storage units: the processor contains a microprocessor that is used to control and execute the protocols and algorithms; for the storage unit, it can be used to store the sensing data, and it is optional and depends on nodes' model and characteristics.

3- Transceiver units: in this unit, the radio system is used in the communication mode with neighbours.

4- Power supply unit: the battery represents the main part of this node; it provides the necessary power to the node and has the main responsibility of the node's lifetime, but because the node size is small, the size of the battery is limited.

Based on the application type, some sensor nodes contain location units that define their position. In some conditions, it is necessary for the nodes to know their position; for instance, in tracking or event-based applications, the nodes should provide the location of the events with the sensing information.

Additionally, a mobilised unit enables the sensor nodes to move in the sensing area based on the sensing task that they perform.

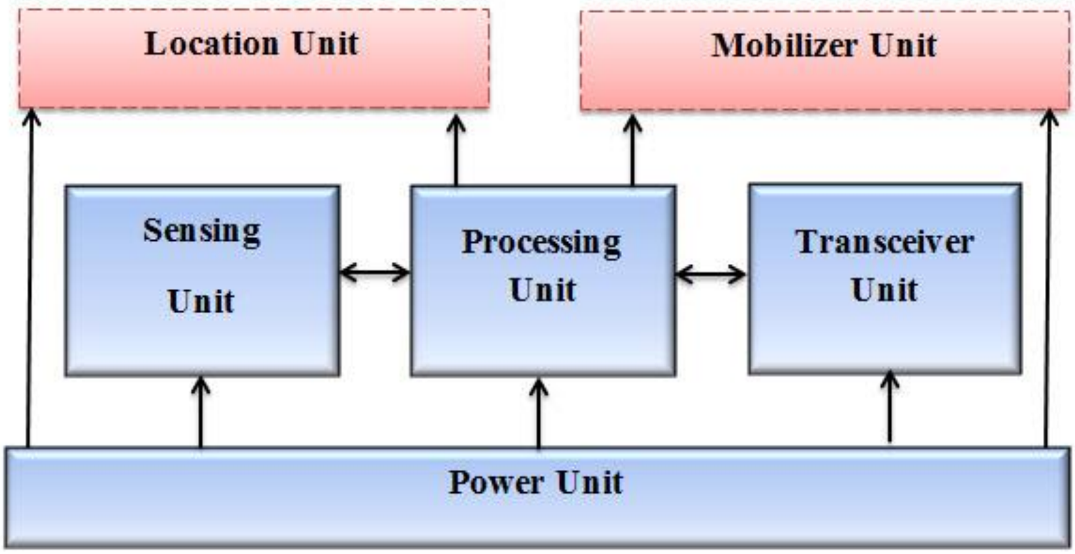


Figure (2-2) Sensor Node's Architecture

2-4 Wireless Sensor Network Applications

The wireless sensor networks can perform various types of high-level applications such as in military operations, health, environment and home monitoring. These applications help to investigate and understand the environment situation easily.

WSNs have the ability to perform many applications that help people to examine and understand the sensed environment easily. The application can be classified according to the reporting type, such as event-based, query based and time-driven based.

There are various types of sensor network applications, and they depend on application requirements such as deployment method, mode of sensing, type of power supply and others (Zhao & Guibas, 2004).

WSN applications are categorised into tracking applications and monitoring applications. Various types of WSN applications are shown in Figure (2-3). This section will briefly introduce different types of these applications.

1- Military Applications: WSN has an important role in the military field. This network can be used for tracking and monitoring military forces and enemy forces, equipment and battle areas (Akyildiz et al., 2002a).

2- Health and Medical Applications: WSNs can be utilised in the health field to monitor patients, such as their blood pressure and heart rate and tracking their movement without the need to stay at the hospital. In addition to this, it can be used to track the doctors' movements (Abidi, Jilbab, & Haziti, 2017) (Dargie & Poellabauer, 2010).

3- Environment Applications: this application represents the first application that was implemented by WSN, as it was used to monitor the environment situation such as seismic system, flood detection, pollution, climate, temperature, humidity, light and pressure as well as monitoring environmental resources such as soil and water quality. In addition to that, it is used in animal tracking and monitors behaviour. WSNs have been widely applied in this type of application (Rajaravivarma, Yang, & Yang, 2003).

4- Home applications: sensor nodes can be used to help people monitor and manage their home devices via a network or the internet (Sadhana, Malik, Gogia, Devi, & Chhabra, 2013).

5- Transportation Applications: this system is used to track and control the traffic flow, car speed, congestion control and other traffic conditions (Dargie & Poellabauer, 2010).

6- Building Applications: recently, sensor networks have been used in structure applications to monitor the building, bridge or a motorway condition and quality. For instance, it is used to monitor the stress, temperature and any cracks occurring in the structure (Buratti, Conti, Dardari, & Verdone, 2009) (Pakzad, Fenves, Kim, & Culler, 2008).

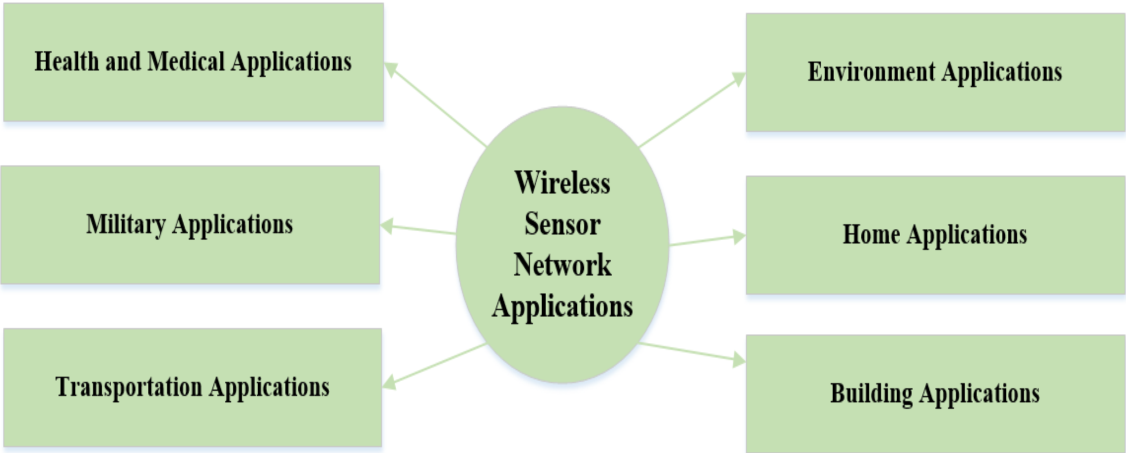


Figure (2-3) WSN Applications

2-5 Wireless Sensor Network Protocol Stack

The protocol stack is the set of layers that is used by the sensor nodes and the sink to process and forward the data from the source to the destination. The main and simplest protocol stack that is used in WSN is shown in Figure (2-4). Each one of these layers performs an individual communication process in the WSN.

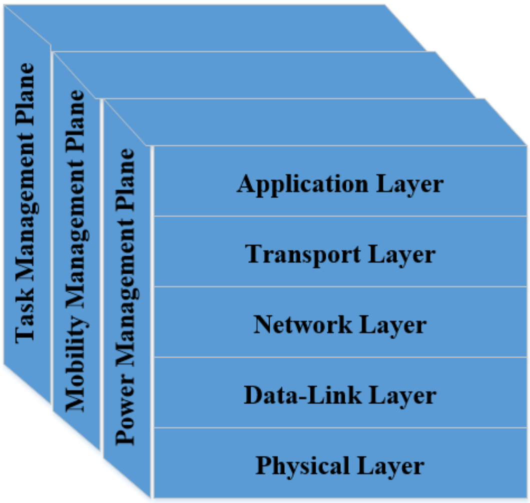


Figure (2-4) WSN Protocol Stack

Basically, in the WSN, the protocol stack consists of five layers, which are: the physical layer, data link layer, network layer, transport layer, and the application layer. Additionally, there are three cross layers, which are power management plane, mobility management plan and task management plane. These added layers are managed, control the network and improve the nodes' cooperation with each other and thus, will improve the network performance(G. Sharma, 2009) (Alkhatib & Baicher, 2012).

The physical layer is responsible for frequency selection, modulation, and demodulation, and receives and transfers the signals. It provides an interface for bits transfer over a physical medium. For the data link layer, it has a Media Access Control (MAC) that is used to minimise the collision among the nodes, error control, connection reliability as well as data stream multiplexing.

The routing function is the primary role of the network layer, which is used to find the optimum route from the source to its destination. Energy preservation is the main challenge in this layer. This layer deals with the data that comes from the transport layer and routes it to its destination. The clustering function is one of the routing functions that should be studied.

For transport layer, the primary role is to provide reliability to control and minimise the data flow in the network based on the application requirements, to provide end to end reliability and security.

The last layer on the top is the application layer, which has the responsibility of representing the required data used software to the users, such as sensor network management. WSN is used in different applications in various fields such as military, medical and environment.

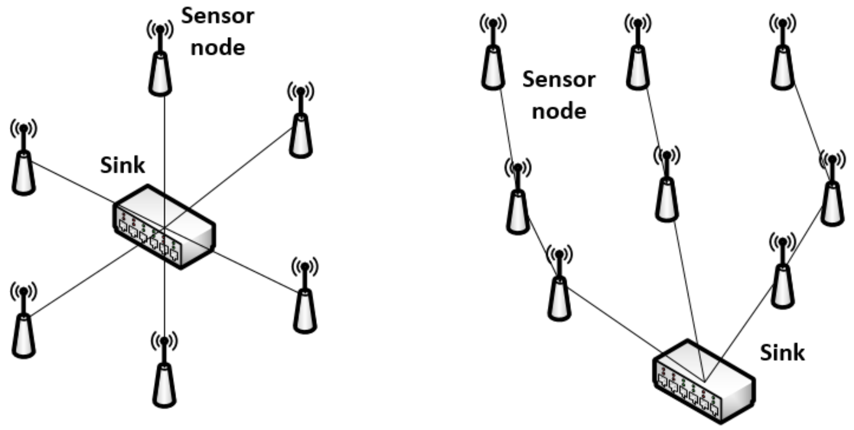
However, the crossover layers have different management functions. The power plane layer is to manage and controls sensor nodes' power usage. In addition, it manage how the nodes can monitor their energy consumption during the performance of different operations such as sensing and communications. In the contrast, the mobility plan layer manages the mobility and movement of the nodes. Also, the sensing and data sending process are controlled and scheduled by the task plane layer (Mir, 2014; Sharma, 2009) (Al-Obaisat & Braun, 2007).

Now, in order to understand the routing function, the next section contains the necessary information about what routing means, the routing protocols classifications, and the available routing protocols and algorithms.

2-6 Routing Protocols in WSN

Routing considers the primary function of the third layer of the protocols stack model (network layer). The routing process is the process of forwarding data from the source (sensor nodes) to destination (sink). Depending on the sensor nodes transmission range, the communication process may occur directly to the sink (single-hop model), and it is like a star topology or via an intermediate node(s) (multi-hops model) forming a mesh topology as illustrates in Figure (2-5) (Dargie & Poellabauer, 2010).

The functions of the routing process in sensor nodes include establishing a connection with adjacent nodes to exchange information, building a routing table and sharing it with other nodes and calculating the best route. The implementation of these functions is achieved using routing protocols and algorithms (Al-Karaki & Kamal, 2005).



(a) Single Hop **(b) Multi-Hop**

Figure (2-5) WSN Communications type

The routing protocols and algorithms are sets of rules that manage the connection between two nodes, control the data transmission from one sensor node to another and calculate the best path to forward data from source to destination depending on certain metrics.

Routing protocols face difficult challenges in the design of WSNs because of their features that make it different from the available types of wireless networks such as MANET. Firstly, in WSN it is impossible to use traditional IP-addressing because of the massive numbers of sensor nodes. IP is used in reliable concoctions (such as cables or fibre optics), and the data error rate is uncommon while in WSN the connection between nodes is wireless, so the error is expected all the time. Thus, traditional networks' protocols cannot be adopted in WSN. Second, all applications in WSN require the transmitted data from multi sources to a single destination (sink). Furthermore, sensor nodes have limited resources such as transmission power, processing capacity and storage so the routing process should manage these resources carefully

(Akkaya & Younis, 2003) (Al-Karaki & Kamal, 2004). According to these characteristics, various types of routing protocols and algorithms have been designed and proposed to implement data routing in WSN.

In WSN design, the routing protocol has been a focus in the research field. Routing protocols and algorithms are application-dependent, and their requirements differ from one application to another; for instance, protocols' characteristics for environment monitoring applications are distinct from that needed for military use (Akkaya & Younis, 2003) (Eslaminejad & Razak, 2012) (Villalba, Orozco, Cabrera, & Abbas, 2009).

The routing communication method in WSN can be classified into the sink to nodes and nodes to sink. It depends on the type of protocol used in the network. For the first category, the sink is responsible for starting the communication process. It is subdivided into the sink to all, sink to one and sink to the group (Chen, Li, Ye, & Wu, 2007). For the nodes to sink, they are used in the data-centric system or networking system. This type has more overhead on node storage, energy and packet control than other types.

2-6-1 Design Requirements for WSN Routing Protocols

As mentioned previously, the sensor nodes have limited battery and processing, and therefore, to design routing protocols and algorithms in WSN, the following requirements should be considered (Al-Karaki & Kamal, 2004; Khurana, 2013; Sharma, 2009):

1- Energy Consumption: this factor depends on the nodes' battery, as the sensor node's failure causes topology changes, rerouting the data and network's reorganisation. To achieve this, the routing technique reduces the number and the size of data that will transfer (Mundada, 2012).

2- Node deployment: this is application dependent. The node deployment may be deterministic (sensor nodes are manually deployed, and their paths are predetermined) or randomise (sensor nodes deployed randomly).

3- Data reporting models: in WSN, sensed data sending from the sensor nodes can be categorised into continuous, event-based, query based and hybrid. In the continuous model, the sensor nodes send their data to the sink periodically at a particular defined rate. In the event-based model, the sensed data sending depends on the event detected. For query based, the sensor nodes send their data only when they receive a query from the sink. Finally, the hybrid model is a mix of the three mentioned models.

4- Fault tolerance: the network should not be affected by any sensor node failure, and that which is achieved by routing protocols should find alternative solutions.

5- Scalability: routing protocols and algorithms should have the ability to manage and control any change in the numbers of sensor nodes; this change may happen by adding or removing sensor nodes to/from the network.

6- Network dynamics: it is application dependent. Sensor nodes and the base station may be in either stationary mode (fixed position) or mobility mode (dynamic position).

7- Connectivity and coverage: this depends on the deployment of the sensor nodes.

8- Data aggregation: this means data collection from different resources and sends it as one packet in order to achieve energy efficiency.

9- QoS: this is application dependent because in some applications, data should be delivered within specified times or it will be useless. On the other hand, saving network energy is more important that data quality.

10- Topology change: the network topology may change because of many reasons, such as node damage and link failure.

11- Node homogeneity/heterogeneity: this is application dependent. Homogeneity sensor nodes mean that all nodes have equal rules in computation, energy consumption and communication. Moreever, heterogeneity refers to the differences in sensor nodes' rules.

12- Applications dependent: the design of routing protocols is application specific, which means that the routing characteristics are based on the network design requirement (Singh & Sharma, 2015).

2-6-2 CLASSIFICATION OF ROUTING PROTOCOLS IN WSN

The routing protocols in this network can be classified according to different parameters such as node location, node functionalities and other parameters; this section will illustrate a review of these classifications and their types. Figure (2-6) summarises the classification of routing protocols and algorithms.

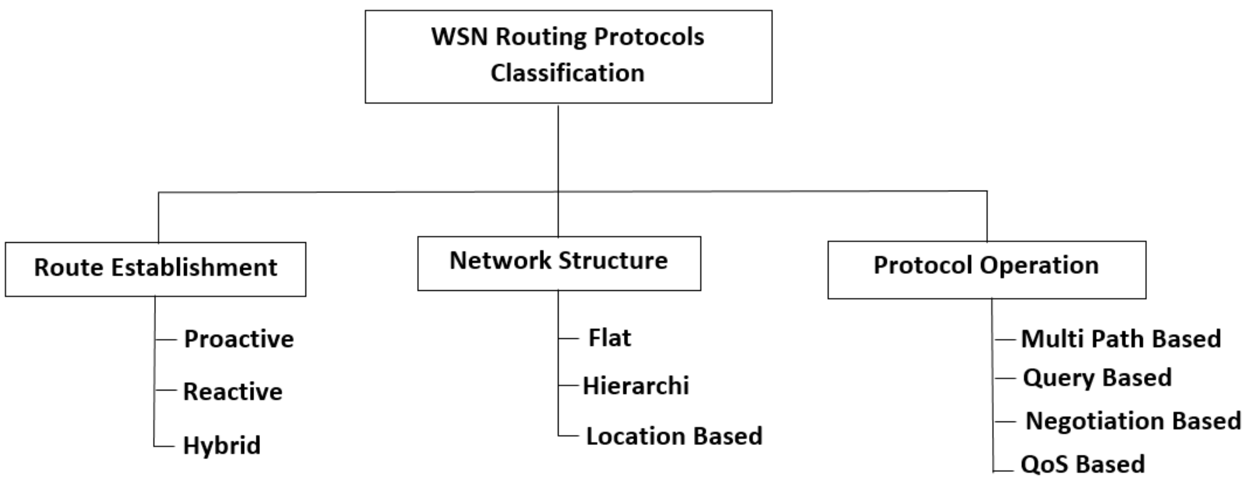


Figure (2-6) Routing Protocols Classifications

2-6-2-1 Network structure-based Routing Protocols

The network structure category divided into flat, hierarchy and location based routing protocols (Singh, Singh, & Singh, 2010) (Cecílio et al.) (Al-Karaki & Kamal, 2004, 2005), as follows:

I. Flat Routing Routing Protocols

All sensor nodes have the same functionality in flat routing protocl, as well as the communication, depend on sink query. The sink sends a query to a particular region and waits for a response from it. As it is query based, attribute-based naming is using for the data requested. There are different protocols, and algorithm examples include flooding, gossiping, Sensor Protocol for Information via Negotiation (SPIN), and Direct Diffusion.

II. Hierarchical and Clustering Routing Protocols

The main goal of Hierarchical and clustering is to reduce energy consumption by dividing the sensor nodes into clusters, and for each one there is a cluster head, which is responsible for managing and controlling all sensor nodes within it. Examples of this type are LEACH, Power-Efficient Gathering Algorithm in Sensor Information System (PEGASIS), Threshold-Sensitive Energy-Efficient Protocol (TEEN) and Adaptive Periodic TEEN (APTEEN). Full details of these categories are described in the next chapter.

III. Location-based Routing Protocols

The protocols classified under this category depend on sensor nodes' location information. This location information can be found by communication between nodes or directly by using GPS techniques if the sensor node has a GPS receiver. This type is also considered to be an energy saver because it allows the nodes to switch to sleep mode if there is no activity with it. Geographic Adaptive Fidelity (GAF), Energy Aware Greedy Routing (EAGR), and Geographical and Energy-Aware Routing Protocol (GEAR) are examples of this type.

2-6-2-2 Protocol Operation based Routing Protocols

Routing protocol in WSN has another important category that is based on the network operation. In this category, the protocols are performed based on the network requirement or what the network needs to operate based on a particular change. The operation-based category is organised into:

I. Query-based Routing Protocols:

The operation of the protocols based on a query where the sink or destination node broadcasts a data request to all nodes in the networks. The sensor node will check if the query matches their sensed data or not, and if there is a match, the nodes send the required data to the sink or the requested nodes. Direct Diffusion and Rumour Routing are classified under this type.

II. Multipath-based Routing Protocols:

In the Multipath-based category, the protocol uses multipath to the sink to achieve high performance. The sensor nodes establish multipath from the source to destination, and this will increase the network reliability and performance and enhance its lifetime. Furthermore, the node can use the other paths to distribute their traffic between them. The best examples of this type are Directed Diffusion and Energy-Aware Routing Protocol.

III. Negotiation-based Routing Protocols:

The operation of the protocols is based on a negotiation process. The nodes use a high-level data descriptor instead of the full data during the protocol process to eliminate the redundant data. After completing the negotiation process and establishing a connection to the required node, the actual data will be sent. The general example of this type is SPIN.

IV. QoS based Routing Protocols:

The protocol should have the ability to balance between data QoS requirements such as delay, sample rate, data accuracy, sufficient bandwidth and energy. The protocols in this type enable the nodes to make a trade-off between the energy consumption metric and various QoS metrics. Examples of this kind are SPEED (Stateless Protocol for Real-Time Communication in Sensor Networks) and SAR (Sequential Assignment Routing).

V. Non-Coherent and Coherent Based Routing Protocols

In non-coherent based routing, the data will be processed in the node before sending it to the aggregator for further processing. Data processing is achieved in three stages; the first stage includes target discovery, data gathering and data pre-processing, while the second phase confirms the connections, and finally, in the third stage the central node will be selected. An example of this type is Single Winner Algorithm (SWE).

However, in incoherent based routing, the level of data processing in the node before sending to an aggregator is limited. The limited processing includes time stamping, duplicating suppression and other. This type is the best choice to use in the energy efficient routing. An example of coherent based routing is Multiple Winner Algorithm (MWE).

2-6-2-3 Routes Establishment

Routing protocols can be classified according to paths calculation process within the network to trasmite the data from the node to the base station. The routes computations classified as follows:

I. Proactive Routing Protocols:

In this type of protocol, the nodes build their routing table to find the route to the destination before needed. The delay in this kind is minimising because the path is ready to use, but at the same time, the bandwidth may increase because of the updated information in the routing table. It is suitable for real-time applications. Examples of this type are Wireless Routing Protocol (WRP) and The Topology Dissemination Based on Reverse-Path Forwarding Protocol (TBRPF).

II. Reactive Routing Protocols:

Demands under these protocols determine the routing tables. It does not need to update the information because the table is already up-to-date, but the delay will increase because the tables are not ready and it should be determined. Examples of this type are: Temporarily Ordered Routing Algorithm (TORA) and Energy-aware Temporarily Ordered Routing Algorithm.

III. Hybrid Routing Protocols:

The protocols in a hybrid are a combination of the properties of the proactive and reactive protocols. This combination occurs because of the communication process between the sensor nodes, which are located in the same area and are therefore near to each other. At the same time, the topology’s changes are significant if the nodes are close to each other and will not affect other parts of network Zone Routing Protocol (ZRP).

Various research and surveys have been carried out in the field of routing protocols in WSN. Full studies of the routing protocols and their classification have been introduced by (Akkaya & Younis, 2003) (Al-Karaki & Kamal, 2004) (Cecílio et al.) (Parvin & Rahim, 2008) (Singh et al., 2010) (Sumathi & Srinivas, 2012). The major factors in the design of routing protocols and the characteristics for each one have been discussed by (Biradar, Patil, Sawant, & Mudholkar, 2009) (Dekivadiya & Vadharia, 2012).

A study by Ramya, Saravanakumar, & Ravi (2016) provided a review of the importance of the energy efficiency routing protocol in the design of wireless sensor network and of enhancing its lifetime; they introduced the available routing protocols as a classification and reviewed the characteristics for each of them.

The available energy efficient routing protocols were studied and discussed in (Devi & Sethukkarasi, 2016). They classified these protocols into different classifications and compared them based on the main parameter that should be taken into account in any routing protocols design.

Among all classifications of routing protocols, the clustering based protocols are the most popular when considering sensor nodes' energy saving. The idea of these protocols is based on dividing the network into clusters, which will be responsible for transferring data between sensor nodes and the sink. The communication with the sink is done via a head node, which is known as the cluster head. Various routing protocols can be classified as clustering-based protocols. Low-Energy Adaptive Clustering Hierarchy (LEACH) was the first protocol that used this technique, and Power-Efficient Gathering in Sensor Information Systems (PEGASIS), Threshold-Sensitive Energy-Efficient (TEEN) Protocol and Adaptive Periodic (APTEEN) are some further examples of this technique. The next chapter will review the basic principles of the clustering function.

2-7 Energy Consumption in Wireless Sensor Networks

Increasing the network lifetime is considered a major challenge in the design of sensor networks. Because of a power source for the nodes is the battery, and the nodes are deployed in an unreachable environment, the battery replacement process is difficult. Accordingly, the designers should take into account energy consumption as the primary consideration in designing any algorithms or protocols (Singh & Arora, 2013).

The source of sensor nodes' power consumption can be divided into useful consumption and wasteful consumption, as shown in Figure (2-7).

The useful consumption includes:

- Communications (including both transmission and receiving): sensor nodes consume most of their power on communication, especially if nodes are located far away from the base station.
- Sensing.
- Data processing.

While the wasteful consumption domains are:

- Collision: A collision occurs when some sensor nodes send data at the same time and on the same channel.
- Overhead and overhearing: overhead means that sensor nodes exchange redundant data while overhearing occurs when a sensor node receives data that are addressed to other nodes.
- Idle/sleep: if the sensor node is in idle mode (not receiving or transmitting any data), it will consume energy. Therefore, power management approaches are used to switch off the nodes when not in use.
- Over-emitting: a sensor node consumes energy sending the data, and the destination is not ready.

Different factors affect the power consumption of the sensor nodes; these factors were introduced in (Kumar & Singh, 2016). The authors stated that some of these factors are communications, collisions, idle and listening modes.

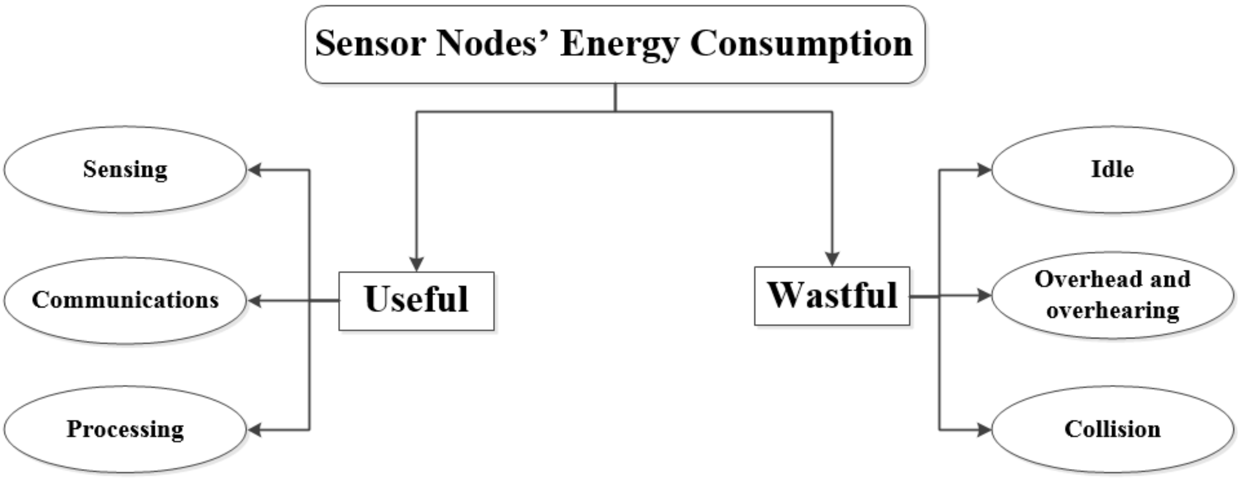


Figure (2-7) Energy Consumption Domains

The highest amount of energy is consumed in the communication field. For example, and based on the research; the power consumption for processing approximately 3000 coded in the processor units is equal to the energy that is consumed to transmit 1 bit of data. Therefore, managing the communication field is necessary to improve the network lifetime (Pottie & Kaiser, 2000) (Ahmedy et al., 2011) (Ali & Roy, 2008) (Anastasi et al., 2006) (Rezaei & Mobininejad, 2012).

One of the primary issues in the design of WSN is the energy management and how its consumption can be minimised. Shaikh & Zeadally (2016) proposed a taxonomy of the available energy harvest sources that can be used in the design of WSN. In addition to that, the paper introduces a review of the available energy models used in energy harvest.

In general, as mentioned previously, the node consists of various components such as transceiver, processor and sensors, and each one of these components has its modes; for instance, in the case of the sensor component, as shown in Figure (2-8), there are only two modes - on an off. The transceiver component that contain the receiver and transmitter have four modes: transmit mode, receive mode, idle mode and sleep mode as illustrated in Figure (2-9). On the other hand, Figure (2-10) represents the processing component, which has three modes: active, sleep and idle. For each mode within the component, there is a certain amount of energy consumption depending on the design criteria and characteristics and sensor node models (Adinya & Daoliang, 2013) (Zhou, Luo, Gao, & Zuo, 2011).

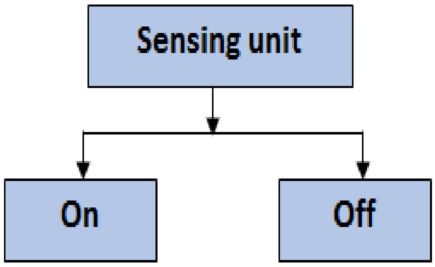


Figure (2-8) Sensing Component Modes

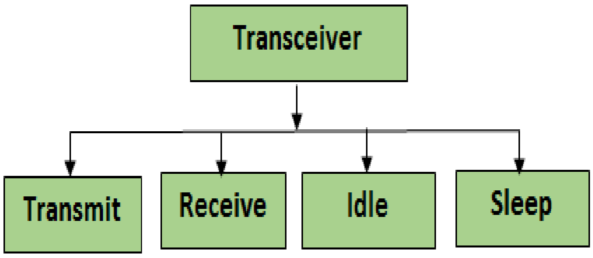


Figure (2-9) Transceiver Component Modes

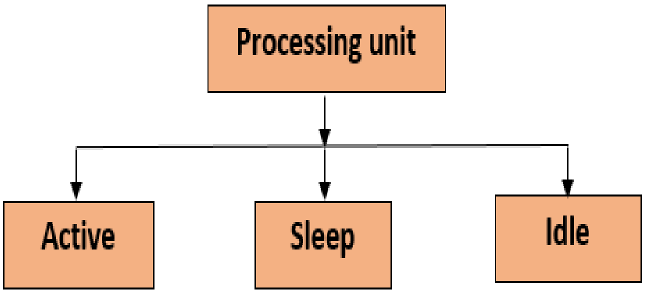


Figure (2-10) Processing Component Modes

The power exhaustion in a routing function is more than other functions because it is based on the communication between sensor nodes, computation process, packet size, sensor nodes status and the distance between sensor nodes and the sink. The aim of most researches has been to find schemes to increase network lifetimes. Some of these plans reduce the number of communications, by minimising the packet size, using efficient duty cycle mechanisms, optimising neighbour selection and reducing the distances that control the on and off status of sensor nodes.

A new energy conservation scheme was proposed by (Pantazis, Vergados, Vergados, & Douligeris, 2009) (Pantazis, Nikolidakis, & Vergados, 2013). This system was based on reducing the end-to-end delay. The researchers recommended using it with a network that monitors rare events and operates for a long time. In addition, (Anastasi, Conti, Di Francesco, & Passarella, 2009) introduced a classification of energy saving methods such as data based and duty cycling based.

The energy saving methods in WSN were presented by (Ali & Roy, 2008). The conservation methods have been classified according to node level, network level and software level. Packet size optimisation have also been used to enhance energy consumption in wireless sensor networks.

However, there are different surveys, which were introduced in this area, such as a study of power saving and energy optimisation techniques as presented in (Sendra, Lloret, García, & Toledo, 2011), where the authors presented the available methods used to reduce the energy consumption in WSN and increase network lifetime.

Meanwhile, the sensor node energy consumption was analysed and introduced in (Sharma, Shinghal, Srivastava, & Singh, 2011), and the mathematical model presented in this paper depends on a proposed sensor node with its characteristics. The results of this model are used to estimate the approximate lifetime of the node. In addition to this, the researchers investigate the amount of energy consumption of the transceiver part of the sensor node.

In routing, routing protocols and algorithms can use these schemes to achieve energy efficiency in networks (Thangadurai & Dhanasekaran, 2013), and energy harvesting has been the objective of much research in this field. (Anastasi et al., 2006) Discussed various approaches such as supplying energy from external sources or saving energy using efficient protocols and algorithms that can save sensor nodes' battery life. A study of sensor nodes' power management was carried out by (Ahmedy et al., 2011).

Energy gains significant attention during the design of new protocols and algorithms in the routing process. The communications among sensor nodes, the packet size, the distance between sensor nodes, the sink, and the sensor nodes' idle mode are the main sources of power dissipation in routing. There are various types of routing protocols whose primary design factor is reducing energy consumption, such as Low Energy Adaptive Clustering Hierarchy (LEACH), Sensor Protocols for Information via Negotiation (SPIN) and Energy-aware routing protocol (Cecílio et al.).

2-7-1 Sensor Node and Network Lifetime

The sensor node's energy level had a significant effect on the Network lifetime, which is an important performance metric in Wireless Sensor Networks (WSNs).

There are three principal ways to determine the network lifetimes (Tian & Georganas, 2002) (Madan & Lall, 2006):

1- The time duration between the start of communication and the time when the first node dies (FND).
2- The time duration between the start of communication and the time when the half of the nodes die (HND).
3- The time duration between the start of communication and the time when the last of the nodes die (LND).

On the other hand, the authors in (Xue & Ganz, 2006) introduce another idea, which is that the lifetime is based on the specified percentage of the dead node, for example when the number of dead nodes reaches the assumed rate; this means that all nodes are dead.

This thesis aims to evaluate the protocol, and the First Node Dead (FND) is the main parameter that will be adopted.

2-8 Summary

From the research conducted, it is clear that a significant development has been occurring in the design of WSN. This network consists of small and battery powered nodes with limited resources (limited energy and memory) cooperating with each other to perform a particular sensing task, and because of the sensor nodes' energy limitations, power management has become an essential factor to be considered during the design of the protocols.

There are various issues concerning the design of this type of network, for instance, the energy constraints, communications among the nodes to perform a task, delivery mode, application type and nodes deployment process.

A brief introduction of wireless sensor networks, sensor nodes' overall architecture, protocol stacks, and routing protocols have been discussed in this chapter. Various types of applications and energy consumption fields in this kind of network have also been reviewed in this chapter.

Furthermore, the definition of routing protocol and its classifications have been provided. In addition, the sensor nodes units that consume energy in different modes such as in transfer, receive and idle, have also been reviewed in detail in this chapter. Finally, this chapter has introduced the main points regarding routing protocol design requirements in WSN, which have been taken into consideration through this research process.

Chapter Three

Literature Review of Clustering Based Routing Protocols in Wireless Sensor Networks

3-1 Introduction

The limited resources of sensor nodes introduce challenges to the design of any routing protocols. By minimising the energy consumption of the nodes, the network lifetime should be improved. However, the clustering function is the most important routing function that should be managed. During the operation of clustering based routing protocols, the sensor nodes consume a significant amount of energy during the implementation of clustering stages. These cluster-based routing protocols are categorised into distributed types, where the nodes are responsible for clustering functions, and centralised types, which are used to improve the distributed clustering protocols. In protocols that are based on a centralised process, the base station is responsible for clustering functions.

In this chapter, the main definition and challenges in clustering approach are discussed. Furthermore, a literature review of related work to existing clustering routing protocols in WSN is presented to be utilised in the design of the proposed protocol in this thesis.

3-2 The Clustering Approach

As mentioned previously, clustering is the process of dividing the sensor nodes into groups known as clusters, as shown in Figure (3-1). For each cluster, a single node will be responsible for all functions within the cluster such as aggregation and processing the data before sending it to the sink, this single node known as a cluster head. The cluster head communicates with the sink directly or via one or multi-hops communications. The main and important aim of the clustering function is to improve the network lifetime (Zhang, Mamalis, Gavalas, Konstantopoulos, & Pantziou, 2009) (Pal, Singh, Yadav, & Pal, 2012) (Abbas & Younis, 2007) (Zhang et al., 2009) (Zhao & Guibas, 2004)

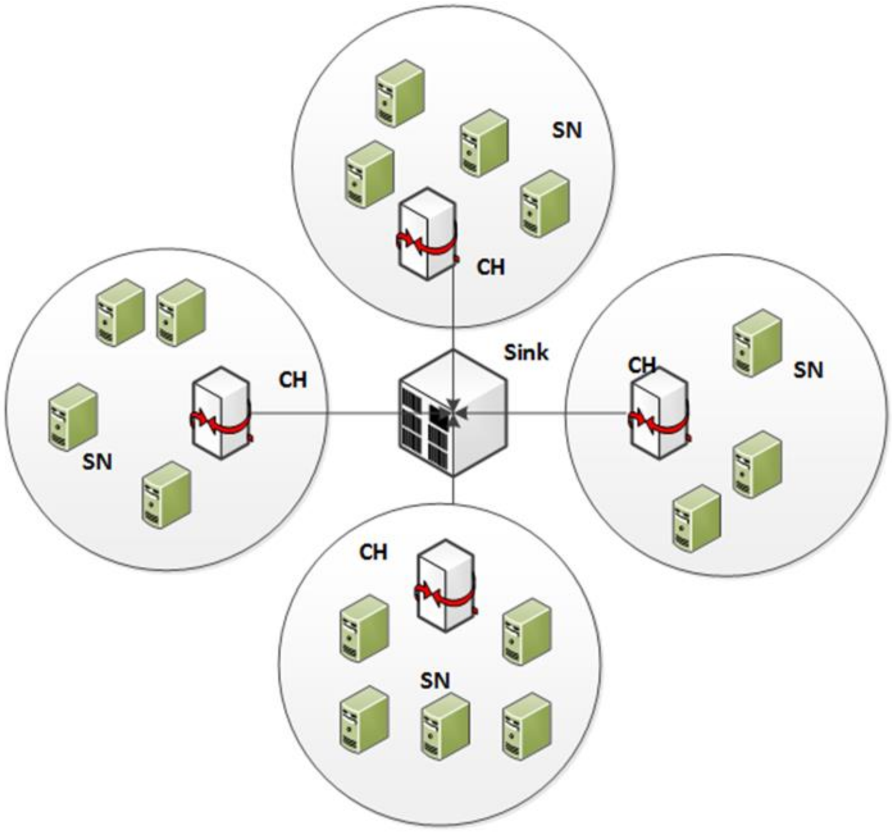


Figure (3-1) Architecture of Cluster-Based Routing Protocols

The clustering function is divided into two stages, the setup stages and steady stages; in the first stages, the cluster head will be selected, and the cluster will be formed, while in the steady-state stage the sensor nodes within the cluster will start sensing the data and send it to the CH that will send it to the sink. Figure (3-2) represents the main stages of clustering.

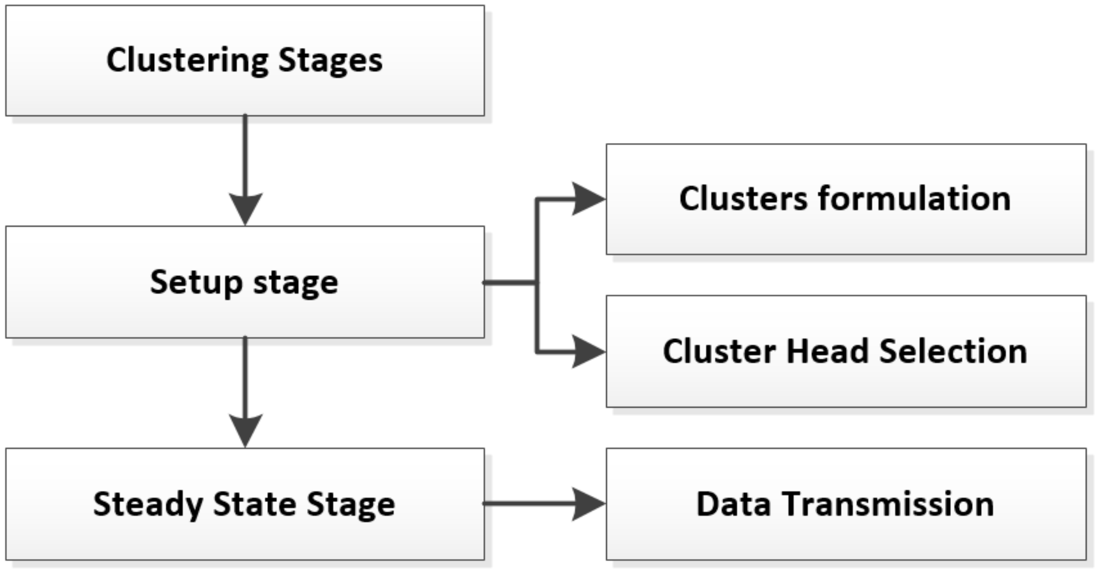


Figure (3-2) Clustering Function Stages

The clusters can be classified based on different properties, as illustrated in Figure (3-3).

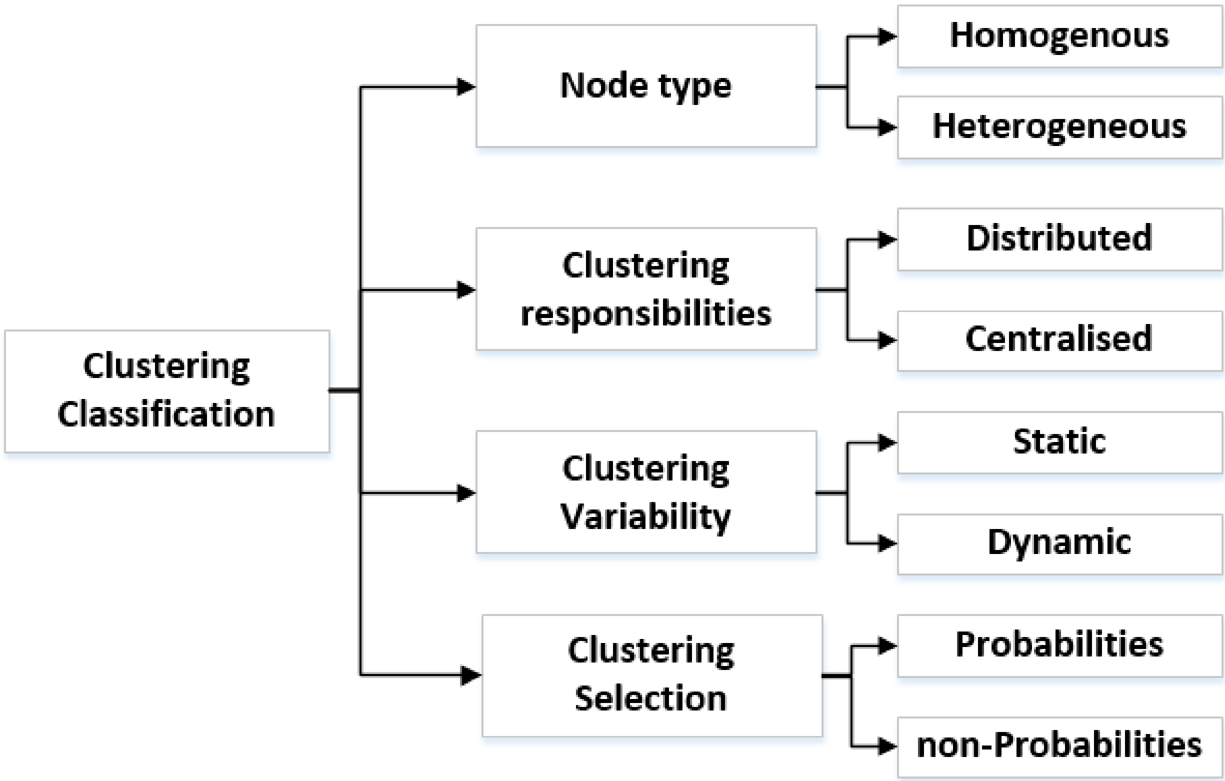


Figure (3-3) Clustering Proprieties

The following list is to explain the clustering proprieties in details:

1- Static vs. dynamic: the clusters formation and cluster head selection performed only once in the static clustering. In this type, the cluster head node will consume all its power and die and thus, will isolate the whole cluster and make it unreachable. In contrast, in dynamic clustering, the clusters formation and cluster head selection change at each cycle or round.

2- Heterogeneous vs. homogenous: In heterogeneous, the sensor nodes are different in their abilities such as in processing and energy level. Therefore, the CH selection will be based on a node with the highest abilities. However, in the homogenous, all sensor nodes have to save proprieties, and all of them have a chance to be CH.

3- Distributed vs. centralised: In WSN this type is the most important. The clustering function implementation can be classified into two main types, the standard and most popular type are the distributed clustering protocols, which means that the clustering function performed by the nodes and the sensor nodes are responsible for clustering decisions. The most popular protocols in this type are LEACH, TEEN, and Hybrid Energy Efficient Distributed Clustering (HEED), PEGASIS: Power-Efficient Gathering in Sensor Information Systems. In contrast, the centralised means that there is a central node/s (generally the sink) responsible for the clustering function. LEACH-C, BCDCP, and LEACH-F. All the available centralised routing protocol is based on the sink function (sink responsible for the clustering function). Also, the main drawback of this technique is the process of sending nodes information that is performed at the beginning of each round.

4- Probabilities vs. Non- Probabilities: In probabilities clustering, the process of cluster formation and cluster head selection is based on a random and non-uniform process.

However, in non-probabilities, the clustering function is based on pre-determined parameters such as node ID, node weight or energy level.

Many design issues should be taken into consideration during the design of any clustering protocol. Some of these problems are the energy constraints and network lifetime. The methods of cluster head selection and cluster formation have a significant impact on the overall network performance, and in addition, scalability, network topology, data aggregation, secure communication, and fault tolerance have important implications for the clustering methods (Singh & Sharma, 2014) (Kumarawadu, Dechene, Luccini, & Sauer, 2008) (Abbas & Younis, 2007).

The clusters have different characteristics, which affect the network lifetime such as:

- Cluster count: the cluster count is the number of clusters formed in one round, and it should balance to achieve energy efficiency (Gupta, Jain, & Sinha, 2013) (Pal et al., 2012).
- Cluster size: is the number of nodes within clusters. It is based on the distance between the nodes within the cluster and should be managed for efficient performance. The smaller size of the cluster, the better the energy efficiency because the communication distance is minimised, and it can be fixed or dynamic. The cluster size may be uniform or non-uniform depending whether the size is the same for all clusters or different (Gupta et al., 2013) (Kumar, Dhok, Tripathi, & Tiwari, 2014) (Liu, 2012).
- Intra-communication: it represents the communication inside the cluster, between the sensor nodes and their cluster head that can be single hop or multi-hops, as illustrated in Figure (3-4a, b) (Gupta et al., 2013) (Kumar et al., 2014).

- Inter-communication: it represents the communication between the cluster heads and the base station, and it can be single hop or multi-hops, as shown in Figure (3-4c, d) (Gupta et al., 2013) (Kumar et al., 2014).

The cluster head selection approaches can be classified into deterministic, adaptive and random. In the deterministic, the selection is based on particular parameters such as an identifier or neighbours' nodes. In the adaptive approach, the selection of the cluster head is based on a certain function such as its energy level or communication cost. Finally, for the random type, the selection is made randomly without regard to any parameters (Liu, 2012).

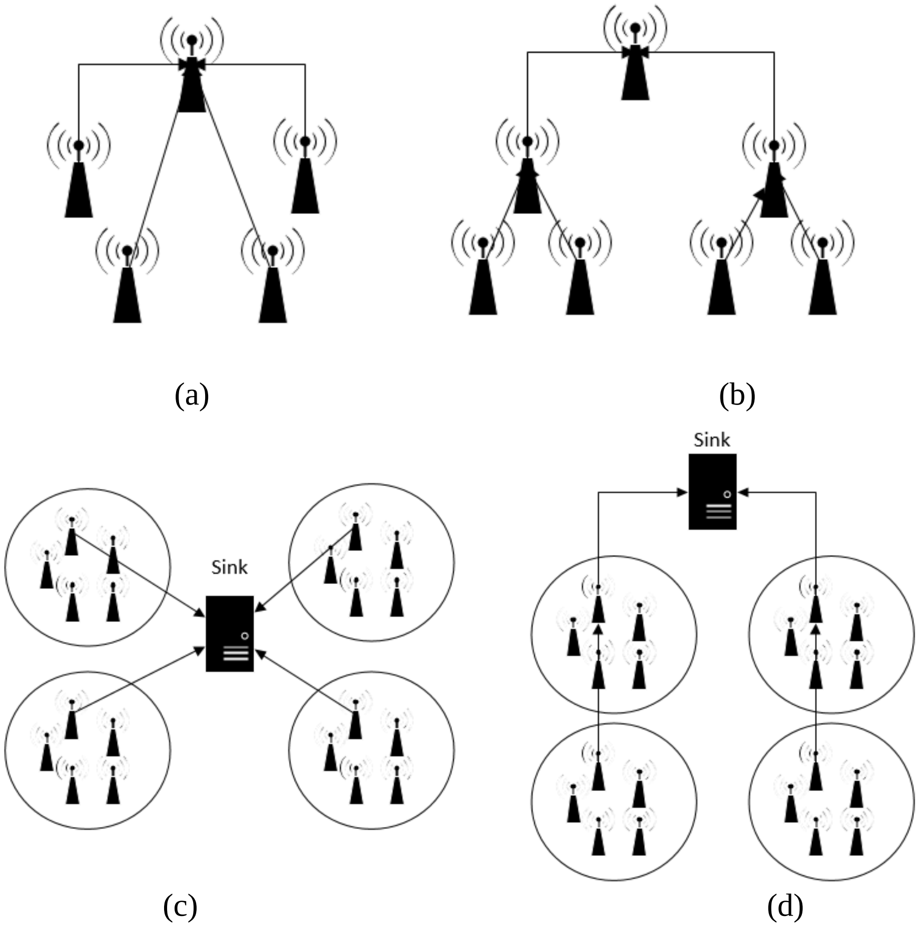


Fig (3-4) Clustering Model

(a- Intra-communication (Single hope), b- Intra-communication (Multi-hop), c- Inter-communication (Single hope) , d- Inter-communication (Multi-hop))

The cycle process of the clustering is divided into rounds, with each round divided into frames as shown in Figure (3-5). For steady-state stages, the frames will be using the Time-Division Multiple-Access (TDMA) schedule to set a time slot for each node to use during the data transmission process (Shigei, Miyajima, & Morishita, 2010).

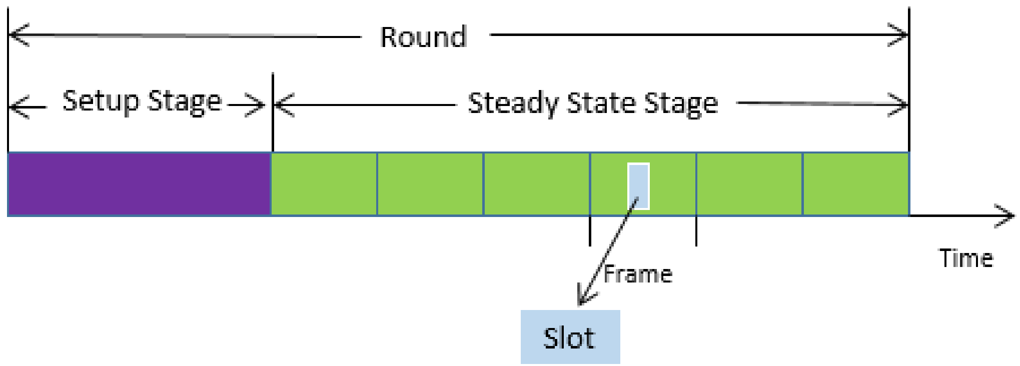


Figure (3-5) Clustering Timing

The sensor nodes send their information to their cluster head once per frame, and at the end of this frame this cluster head will aggregate the data and send it to the sink once per frame.

The main drawback of the clustering function is the communications, which is the key issue in the design of this function domain that includes inter communication between the cluster head and the sink and the intra communication among the sensor nodes and the cluster head. Furthermore, the cluster head nodes spend more energy in communications and calculations, and this is considered an issue in designing any clustering protocols (Singh & Aloney, 2015) (Patil, Kulkarni, & Ayachit, 2011).

The communication cost is divided into two types: before clustering cost and after clustering cost. The before clustering cost is the communications that are needed to perform the clustering function, form the clusters and select the cluster head node, while the after clustering cost is based on the intra cost of communications. This type is among the sensor nodes and inside the cluster itself, while the inter cost is the communications cost between the cluster head and the sink. Thus, it is essential to manage these communications costs in order to make the clustering process more efficient (Tripathy & Chinara, 2012).

(Arboleda & Nasser, 2006) Investigate the concept of the clustering techniques such as cluster elements, cluster advantages and cluster types, and in addition to that, they introduce a survey of various clustering algorithms and protocols and list the main differences among them.

In order to understand the different classifications on the clustering algorithms, the author (Abbas & Younis, 2007) introduces a clustering taxonomy that classified the clustering algorithms and protocols according to their design objectives such as energy consumptions, coverage, mobility, position, and load balancing.

The cluster heads selection methods are changeable and different from protocol to protocol, as summarised in the survey (Thakkar, 2016). In this research, the author focuses on the hierarchical routing protocols types and reviews the available protocols and their characteristics for both homogeneous and heterogeneous networks with station nodes to introduce a full taxonomy of these techniques. Furthermore, various clustering approaches had been investigated in (Ramesh & Somasundaram, 2011). The authors reviewed the exiting algorithms based on their costs in cluster head selection, transmission as well as the requirement for the cluster head rotation. It concludes that the available algorithms need more study in terms of scalability and energy efficient in WSN.

A taxonomy of the clustering algorithm was introduced in (Singh & Sharma, 2015). In this paper, the metrics and the limitations of the clustering functions were described, and the authors proposed future work be done in the field of clustering in WSN.

Regarding the mobile WSN, the (Sabor, Sasaki, Abo-Zahhad, & Ahmed, 2017) studied and explained some of the available hierarchical and clustering based routing protocols that had been proposed in the last five years. The survey contained a compression between the protocols based on delay, network size and energy efficiency as well as illustrate the advantage and disadvantage for each protocol.

In this thesis, the concept of the k-means algorithm is adopted to cluster the network during the implementation process, and a full explanation of this algorithm is introduced in the next chapter.

3-4 Clustering Based Routing Protocols

In general, the important classification of clustering based routing protocols is who is responsible on clustering function; it can divided into distributed or centralised protocols as illustrated in Figure (3-6). The full details of each category will be described in the next sections.

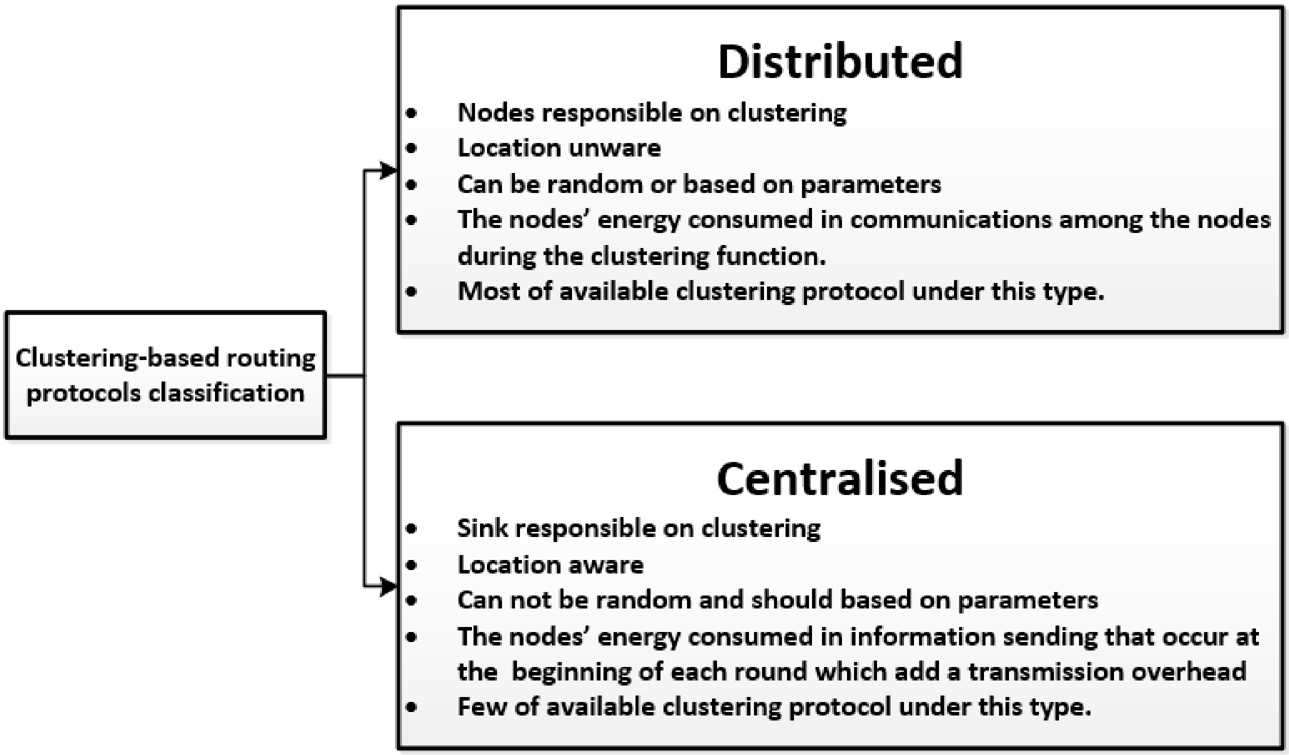


Figure (3-6) Clustering Routing Protocols classification

3-4-1 Distributed Clustering Protocols

In the distributed protocols, the clustering function is based on the communications among the sensor nodes to perform the clustering function and manage the network. Additionally, the nodes are considered to be location-unaware, which means that they do not have any information about their location and other nodes' location within the network. Hence, the clustering decision is based on internal information. According to this, the energy consumption of the clustering causes an extra overhead regarding communications; this will maximise the energy consumption of the nodes and affect the network lifetime.

With this type, the available protocols focus on the cluster formation or cluster head selection techniques. However, regarding the number of communications, the same procedure is used which shown in Figure (3-7).

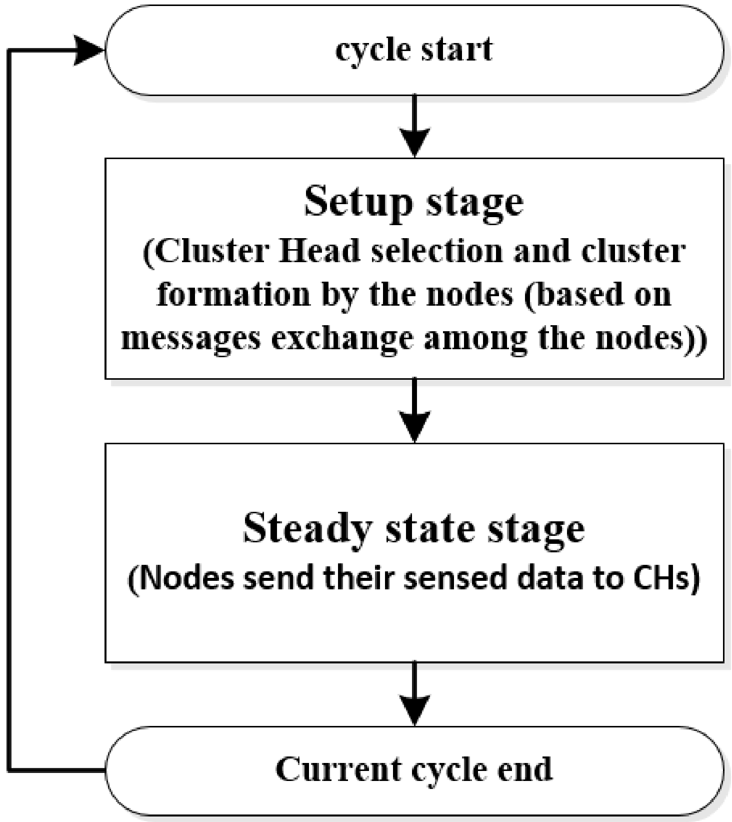


Figure (3-7) Distributed Clustering Protocol Flowchart

The first protocol in this category is the base for the work for all the existing clustering based protocols (LEACH) and will be discussed in the next section.

1- Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is the first and most well-known clustering based protocol in WSN which had been proposed in (Heinzelman et al., 2000). The purpose of this protocol is to minimise the energy consumption and improve network lifetime. LEACH has been classified under the distributed type, where the nodes themselves are responsible for clustering function (cluster head selection and cluster formation).

LEACH uses a random scheme to select CHs and form the clusters in the network and thus, increases network lifetime by distributing the energy consumption among the SNs. In addition to that, the clustering proprieties are dynamic, which means the CH selection and cluster formulation changes after t time (Pawa, 2011). This randomisation process leads to the problem that the clusters will not be distributed uniformly to cover all the network area.

The round of the LEAH is divided into two stages, the setup stage and steady state stage. In the first stage, the CH will be selected, and the clusters will form while in the second stage the SNs will start to send their data to its CH that will send it to the sink (Al-Karaki & Kamal, 2005) (Pawa, 2011). The round's timeline for this protocol is illustrated in Figure (3-8) (Vashist & Khurana, 2013).

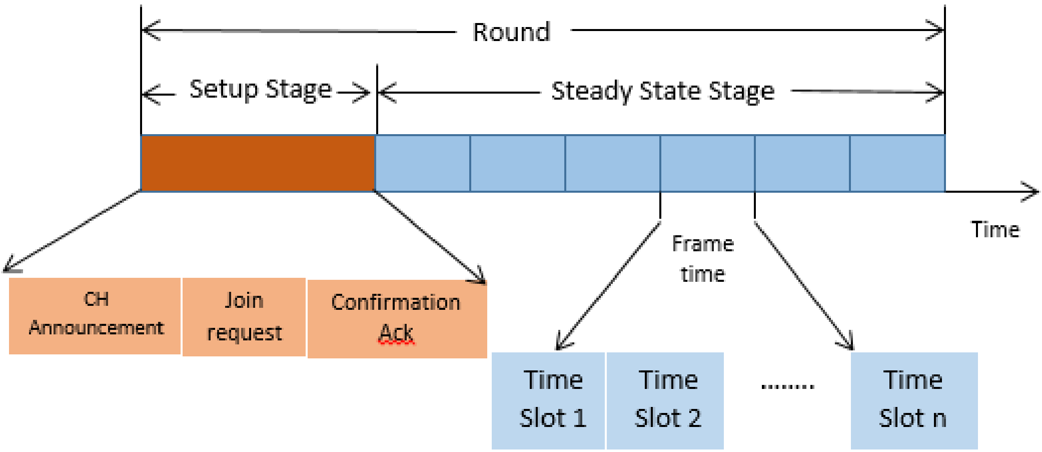


Figure (3-8) LEACH Round Timeline

The time for the steady state stage is divided into frames; the number of frames depends on the number of sensor nodes in the clusters within the network. Inside each frame, the time is divided into multi-time slots depending on the number of nodes in the cluster. The sensor nodes forward their data to the cluster head once per frame and at their predefined time slots. At the end of each frame, the cluster head aggregates the sensed data and sends it to the sink directly (Heinzelman, Chandrakasan, & Balakrishnan, 2002) (Vashist & Khurana, 2013).

In the setup stage, each SN generates a random number between 0 and 1, an assumption of predetermined value (p) that represents the desired CHs in the network; then, each SN will calculate the threshold value T(n) using the following equation.

$$T(n) = \frac{p}{1-p\left(r(mod(^1/_p)\right)} \qquad \text{Where r is current round number}$$

If the SN's random number is less than T(n), this SN will announce itself as CH for the current round. Otherwise, it will wait for an announcement from another SN to join their clusters, and all non-cluster nodes should be in on mode waiting for any cluster head announcements. LEACH uses TDMA in the communication to avoid the collision. The simple diagram of this operation is shown in Figure (3-9) (Al-Karaki & Kamal, 2005) (Hou, Tang, & Noel, 2013).

Despite LEACH being considered an energy efficient routing protocol compared with other data-centric protocols, it has many drawbacks, as listed below (Enam, Imam, & Qureshi, 2012; Ramesh & Somasundaram, 2011) (Tong & Tang, 2010):

- The clustering is unbalancing and may not cover all the network area.
- The inefficient cluster head selection scheme is based on probability and random selection, and does not consider the remaining energy of the sensor nodes. Therefore, the nodes with low energy level may be selected as a cluster head, and this will lead to increased power consumption for the nodes.
- The random selection of the CHs makes it difficult to predetermine the CHs to distribute it uniformly to cover the whole network area.
- The dynamic clustering may cause an overhead on the network, and it does not take into consideration the SNs position and location.

Regarding communications that take place during the functioning of this protocol, Figures (3-10) illustrate the number of transmissions and receiving processes in both cases, for cluster head node and cluster member nodes. It is noticeable that there are a significant number of communications during the protocol activities and this leads to increasing the amount of energy consumption and affects the network lifetime. Therefore, this should be controlled and managed to improve the network lifetime, and this is one of the main thesis contributions.

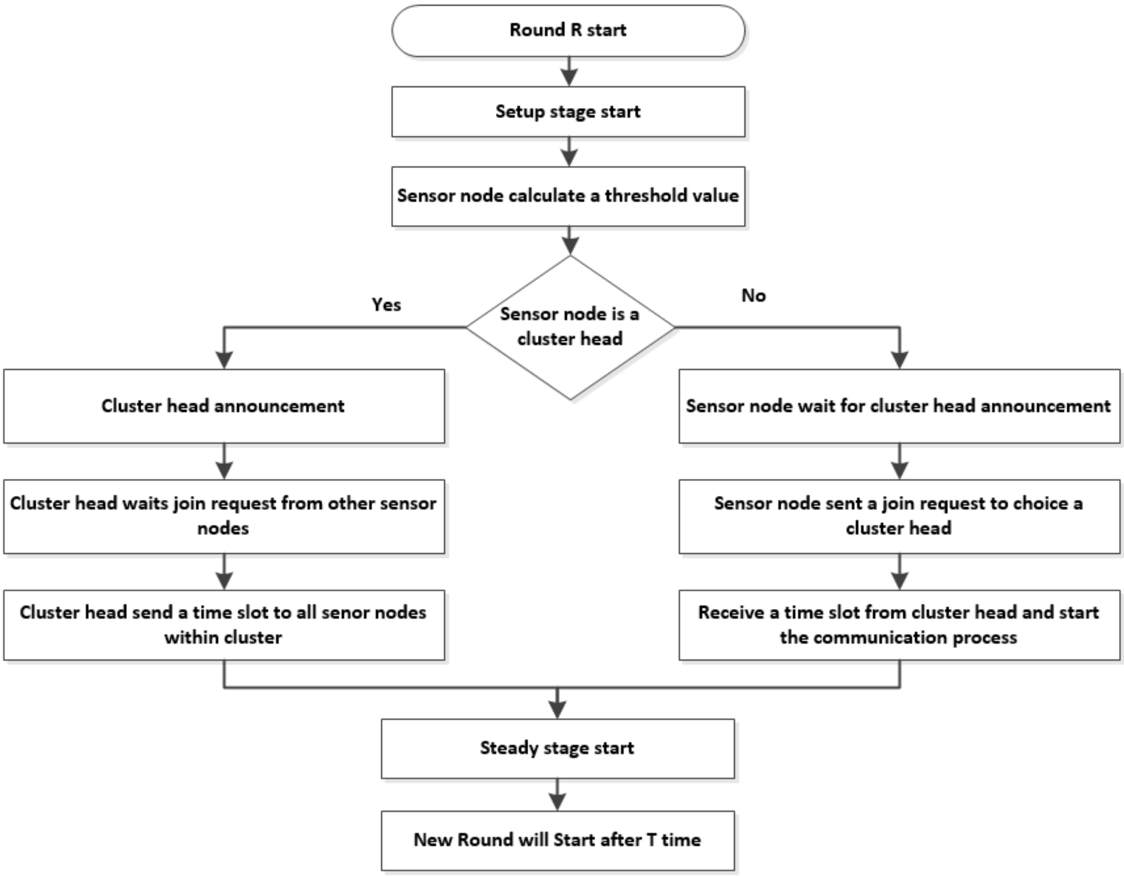


Figure (3-9) LEACH Operation Flow Chart

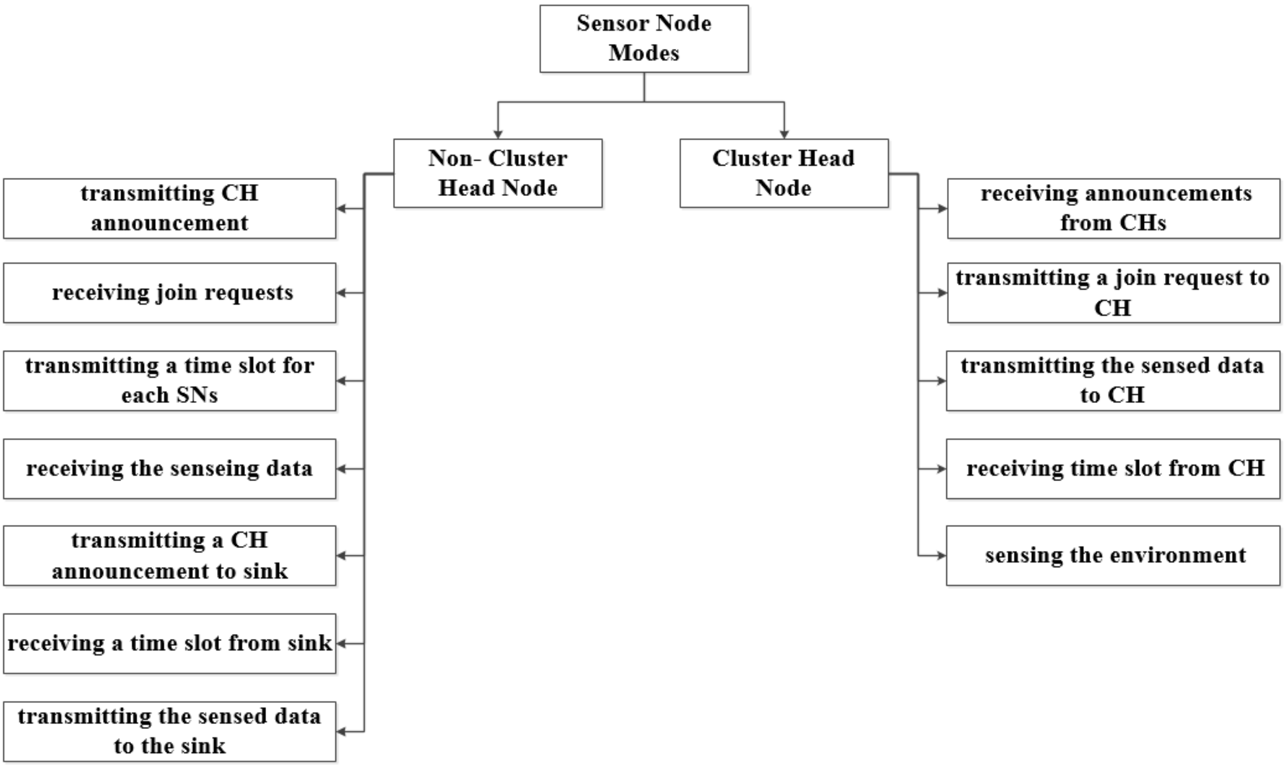


Figure (3-10) LEACH Communications Fields

Owing to LEACH's popularity, there are various studies that have been introduced in this area. The implementation of this protocol in the real time is introduced in (Hou et al., 2013) which is the first implementation of LEACH protocol in the real wireless sensor nodes, where the implementation is based on the TinyOS and Crossbow MICA2 hardware platform, and it is considered a significant contribution in the field of WSN.

There are various studies and surveys that have been proposed based on the principles of this. For instance, the authors in (Mahboub, Arioua, & Ez-Zazi, 2016) (Aslam et al., 2013) (Aslam et al., 2012) (Bhakti Parmar, 2014) (Hani & Ijjeh, 2013) (Kaur & Grover, 2015; Sheth & Rathod, 2015) (Upadhyay & Swaroop, 2016) introduce surveys and reviews on the different types of protocols whose functions are based on LEACH.

Most of the available distributed clustering routing protocols are based on the concept of LEACH protocol and each one of this protocol try to enhance the LEACH protocol and improving the network lifetime. Some of these protocols will now be discussed in next section.

2- LEACH-Balanced (LEACH-B):

To enhance the cluster head selection process in LEACH, the LEACH-B is proposed in (Tong & Tang, 2010). In this protocol and during the first round, the cluster head selection follows the same procedure as in LEACH while the second selection based on node's remaining energy. The selection technique makes the number of cluster heads near the optimum and thus will lead to balancing the energy consumption; the result shows that this protocol is better than LEACH in terms of energy consumption, and it maximises network lifetime, but at the same time it increases network overhead during the cluster head selection.

3- Extended-LEACH (E-LEACH)

Extended -LEACH (Xiangning & Yulin, 2007) improves the cluster head selection scheme of LEACH. The decision of cluster head selection based on nodes energy level. As in LEACH, the protocol operation is divided into rounds, for the initial round, all the nodes have the probability of being a CH, so its random process. While in the following rounds, the nodes with high energy level will be a cluster head for the current round. The results show that the network lifetime in the E-LEACH is longer than LEACH.

4- Energy-Efficient LEACH (EE-LEACH)

To improve the network lifetime, a Gaussian distribution model was used in EE-LEACH (Arumugam & Ponnuchamy, 2015) for better coverage in the sensing area. The cluster formation and cluster head selection are based on nodes energy level. The results illustrate that the EE-Protocol is better than LEACH in terms of energy consumption reduction and packet delivery ration. This work focused on how to reduce the energy consumption, but it had lacked in the security issues and attacks.

5- Energy Efficient Extended LEACH (EEE-LEACH):

As mentioned previously, the communication in LEACH protocol is single hop. Therefore, to minimise the distance between the nodes in order to minimise the energy consumption, the EEE-LEACH clustering protocol is introduced in (Pare & Dongre, 2015). This protocol based on multi-level communication and a new master node are selected to cooperate with the main cluster head during data processing. The results show the new protocol is more efficient than LEACH and the network lifetime had been improved.

6- Power-Efficient Gathering Sensor Information Systems (PEGASIS):

The concept of the protocol is based on chain clustering (Lindsey & Raghavendra, 2002), a chain of nodes formed from the nodes to the sink. The chain formation is based on a greedy algorithm. To reduce the overhead that occurs in the clustering function, but it adds a new overhead related to chain shaping. The results show that network lifetime and performance under PEGASIS is better than the LEACH.

7- PEGASIS-LEACH:

To improve the PEGASIS and LEACH protocols, an optimum cluster-based chain protocol proposed in (Razaque, Abdulgader, Joshi, Amsaad, & Chauhan, 2016). This protocol is gathering the fundamentals of the LEACH and PEGASIS to improve the energy efficiency. In other words, its combine the chain formation scheme with the clusters in data forwarding. The results shows that the new protocol outcome the LEACH and PEGASIS in terms of energy consumption, the number of dead nodes and network lifetime.

8- Threshold sensitive Energy Efficient Sensor Network Protocol (TEEN):

To improve the performance of the LEACH to work in criticial application, an energy efficiency routing protocol for reactive networks known as TEEN (Threshold sensitive Energy Efficient Sensor Network Protocol) is introduced in (Manjeshwar & Agrawal, 2001). TEEN protocol can be used in a reactive network where the nodes react immediately to any changes in the sensing environmet. Therefore, this protocol is suitable to work in time critical applciations.

In this protocol, two thresholds sensed attribute, hard and soft threshold, are used to enable the SNs to sense the critical conditions and prevent them from sensing the data continuously, which will reduce the energy consumption. The main drawback in this protocol is that if the threshold values do not reach the SNs, they will stop communication and sensing and will not be used in periodic applications.

9- Adaptive Periodic-TEEN (APTEEN):

Because of the TEEN protocol is suitable for the reactive network only, an extension of the TEEN protocol APTEEN (Adaptive Periodic-TEEN) is proposed (Manjeshwar & Agrawal, 2002) to be used in both proactive and reactive mode networks (Hybrid networks). The nodes participating in the transmission are only the nodes with sensed data at or below the threshold value. Its main drawback is in TEEN, which is the extra overhead, and the complexity of clustering function in multi-level.

10- LEACH-Selective Cluster (LEACH-SC):

In order to improve the cluster head selection process in LEACH, (Iqbal et al.; Jun, Xin, Junyuan, & Zhengkun, 2010) propose a routing protocol known as LEACH-SC (LEACH-selective cluster). This protocol is considered to be a distance-based clustering protocol, and the author assumes that the SNs know their locations and positions. A new scheme is used during cluster head selection to achieve energy efficiency. The SNs join the CH that is nearest to the middle point in the distance between the SN itself and the sink. In the results, this protocol outperforms the LEACH protocol in terms of energy consumption and prolonged network lifetime.

11- Narrative-LEACH (N- LEACH):

To optimise the nodes energy level and improve the Intra and inter communication of LEACH, a clustering protocol based on LEACH called narrative-LEACH is proposed in

(Tiwari, 2016). This protocol uses the multi hop scheme to optimise the energy of the network. The cluster head selection in this protocol is based on a tree where any node that is in the tree can reach the sink while there is nothing like this in LEACH. The results show that the new protocol is the outcome of the LEACH protocol and improves the network lifetime. In spite there is an improvement in the lifetime, but the drawback of is protocol is in using the multi hope communication that causes an extra overhead on the nodes near the sink.

12- Two Level LEACH (TL-LEACH):

As described in LEACH which is suitable for low density networks, and in order to improve this, a random and distributed protocol is proposed in (Loscri, Morabito, & Marano, 2005). The protocol operation based on the two-level hierarchy to allow for better energy consumption especially in high density networks. The role of the primary and secondary cluster heads is rotated randomly. The results show that the new protocol is better than LEACH and the network lifetime had been improved by 30% than in LEACH.

13- Double Cluster Based Energy Efficient Routing Protocol:

In WSN, the most important aim is to prolong network lifetime. According to this, a routing protocol known DL-LEACH which based on LEACH is proposed in (Li & Liu, 2016). This protocol improved the cluster head selection of LEACH. In LEACH, the CH selection is random while in DL-LEACH, the selection of the cluster head depends on the nodes energy level and the distance between the nodes in order to make the selection more reasonable and balane the energy consumption among the nodes. The CH selection had two levels, the first level is where the data is received, while the second level is responsible for forwarding the data to the sink. According to the results, the protocol improves the network lifetime by 75% more than the LEACH.

14- Cognitive LEACH:

There are various researches in order to improve the LEACH protocl. All the avaiables reseraches enhanced either the cluster head selection or cluster formation schems. One of thes research is the protocol known as Cognitive Improved LEACH that proposed in (Rahman, Miah, & Sharmin, 2016). In this protocol, the author changes the cluster head selection, which is based on the ratio of the nodes' current residual energy and an initial energy and multiplies by the root square of nodes' neighbours. The protocol is evaluated with LEACH in two level homogeneity networks, and the results show that the new protocol improves the performance of the network and increases its lifetime.

15- Solar LEACH (S-LEACH):

As the sensor nodes are battery powered, energy saving is considered the most important factor to keep the network working. To utilities from the renewable energy sources such as the solar energy supply, a protocol known as LEACH (Solar LEACH) is proposed (Voigt, Dunkels, Alonso, Ritter, & Schiller, 2004). This protocol is based on the concept of LEACH and the solar system. The aim of this protocol is to make the cluster head selection process based on the node with high solar power. The simulation result shows that this new protocol had a significant impact on the network behaviour and increased the network lifetime.

16- Hybrid Energy-Efficient Distributed clustering (HEED):

By changing the cluster head selection process of the LEACH, a protocol known as Hybrid Energy-Efficient Distributed clustering (HEED) is proposed in (Younis & Fahmy, 2004). The CH selection is based on the nodes energy and the intra-communication cost as well as multi hop communication. The result shows that the network lifetime had been improved with the operation of the new protocol. The clustering performing in each round is the same as in LEACH, and this will cause extra energy consumption and affect the network lifetime. Also, because it uses multi-hop communication, this will cause the death of the nodes early, especially near the sink because of the heavy load that they perform.

17- Unequal Cluster-based Routing protocol (UCR):

As mentioned previously, in multi hop clustering, the nodes close to the sink will drain its energy faster than other nodes, therefore, to minimise the effect of this problem and improve the performance of HEED protocol, (Chen et al., 2007) proposed an Unequal Cluster-based Routing (UCR) protocol. The protocol form the clusters with different sizes based on the distance to the sink. The size of the cluster whose cluster head node is closer to the sink will be smaller than the other that is further away from the sink. The simulation shows that there is an improvement in terms of network lifetime more than HEED.

18- Centralised Energy Efficient Distance (CEED):

A Centralized Energy Efficient Distance (CEED) routing protocol is proposed in (Gawade & Nalbalwar, 2016). In this protocol, the nodes deployment is random, and the cluster head selection is optimised based on the probability process, also the protocol based on multiple systems where only the cluster head nodes near the sink can forward the data. The results show that the protocol improves the system and more so than other routing protocols such as LEACH.

19- Unequal Clustering Routing for Mobile Education Protocol:

To utilities from the clustering protocol in learning and education applications, a novel energy balancing unequal routing protocol for mobile education (mobile learning) proposed in (Zhang, Liu, Zhang, & Liang, 2017). The clusters formed based on a circle area with the sink as the centre. These circles area had a various radius in order to balance the energy consumption. Simulation results show that the network lifetime had been prolonged and the energy consumption of the nodes had been balanced.

20- Double-phase Cluster-head Election Clustering Protocol (DEC):

Heterogeneity of the nodes should be taken into consideration during the designing of clustering protocol. Therefore, a novel distributed clustering protocol had been proposed. The cluster head selection based on a double phase selection scheme. The selection process had two steps, in the first step, a temporary cluster head will be selected based on its initial energy and current energy level. While in the second step, a new node with high energy level among the cluster members will be selected as a new cluster head and replace the old one. This scheme enables the nodes with more energy level to be a cluster head. The results show that the new protocol had better stability than the existing heterogeneous clustering protocol.

21- Energy potential-LEACH (EP-LEACH)

EP-LEACH (Xiao, Zhang, & Dong, 2013) based on EH-WSN (Energy Harvesting WSN) to improve the network lifetime of LEACH protocol. In EH-WSN, the nodes have the ability to harvest their power from the environment and have a rechargeable battery. The process of EP-LEACH is same as LEACH with two different modifications. For the first modification, the node that has more energy harvest level have a high change to be a cluster head. Accordingly, the nodes can become a CHs with an ultimate number of times. The results showed that the EP-LEACH is better than LEACH in terms of network lifetime, but it has poor performance in terms of complexity and message overhead.

3-4-2 Centralised Clustering based Routing Protocols:

The advantage of the centralised clustering that uses the network topology information in order to form good clusters in the network to minimise the amount of energy consumption during the clustering function. The protocols based on the centralised classification that is location-ware where the nodes know their location and are used during the clustering function. The clustering function and all necessary information are performed by central nodes, in general, is the sink, and all the available protocols use the sink as the controller node. The nodes should send their information at the beginning of each round to the sink to start the clustering function but the main difference with our contribution is in this step, where the server is responsible for network management, and the nodes need to send their information at the beginning of the initial round only. After sending their information, there are no communications between the nodes during the cluster formation. The general flowchart for this category and all available clustering routing protocols are flow same steps is shown in Figure (3-11).

A survey of available centralised protocols is introduced in (Zanjireh & Larijani, 2015), where the authors aimed to introduce a full taxonomy of available centralised protocols in WSN. The available centralised clustering protocols are as follows:

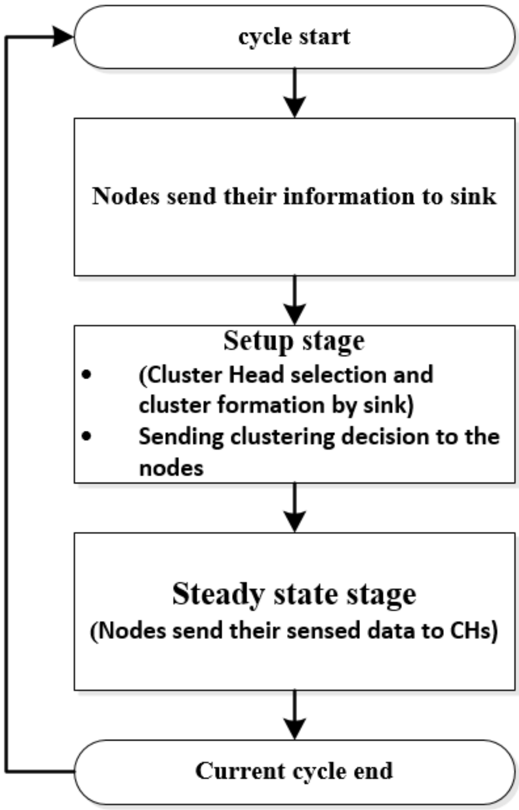


Figure (3-11) Centralised Clustering Protocol Flowchart

1. Centralized LEACH (LEACH-C):

The first centralised protocol is (Centralized Low Energy Adaptive Clustering Hierarchy) (Heinzelman et al., 2002), and the aim of this protocol is to produce better clustering than LEACH. The sink is responsible for the clustering process, and the steady state is the same as in LEACH. The sensor nodes should know their position while the sink clusters the nodes based on specific energy level cluster heads from the nodes that have energy above the average energy level. The sink produces a table with the nodes that are efficient enough to be cluster heads and sends it to the network. The sink uses an optimisation algorithm to determine the optimum number of clusters, and the table of cluster head nodes will be fixed. The operation steps for this protocol is as shown in Figure (3-12).

The LEACH-C protocol shows improvement of 40% more than LEACH regarding network performance. The main drawback is sending information process at the start of each round. This step consumes additional energy for all nodes; will increase the overhead energy consumption regarding communications. Furthermore, the list of CHs nodes is unchangeable that lead to unbalancing the CH selection among the whole nodes in the network.

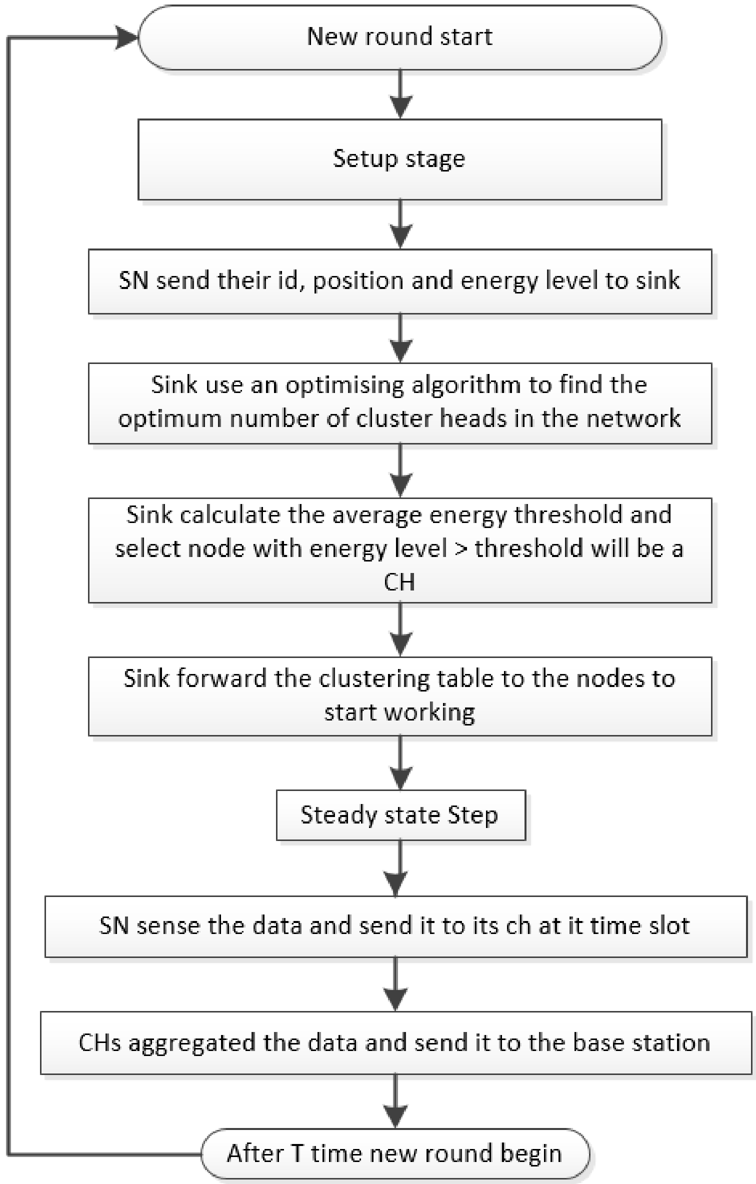


Figure (3-12) LEACH-C Operation Flow Chart

2. Modified LEACH-C:

In order to improve the cluster head selection process in LEACH-C, A modified LEACH-C protocol is proposed in (Parmar & Thakkar, 2016), and this protocol uses the distance between the CHs and cluster members as well as the distance between cluster members and the sink as the main parameter. According to the simulation, the results explain that this new protocol improves the network lifetime and it is better than the LEACH-C protocol.

3. LEACH Central Constrained (LEACH-CC):

To balance the energy consumption for the nodes and improve the cluster head selection in LEACH-C and modified LEACH-C, a develpoed protocl was introduced in (Parmar & Thakkar, 2016). The change was in the process of cluster head selection by changing the range of the nodes that will be cluster heads to be based on their energy level. The simulation results show an improvement of the network performance with LEACH-CC than LEACH-C in term if network lifetime.

4. Energy Efficient LEACH-C (EELEACH-C):

To enhance the network lifetime and minimise energy consumption, a version of LEACH-C is proposed in (Parmar & Thakkar, 2016), using an energy efficient LEACH-C protocol for wireless sensor network. The cluster head selection is based on a sort of algorithm operated by the sink, and the sink creates a list of nodes sorting in descending order based on their energy level. The node with maximum energy level will be a cluster head for the current round. Whilst there is an improvement in the network with this protocol, the main drawback is if there are two nodes with the same energy level, the node that will be a cluster head is based on nodes id, which is not an efficient method.

5. Base-Station Controlled Dynamic Clustering Protocol (BCDCP):

Another centralised clustering protocol is introduced in (Muruganathan, Ma, Bhasin, & Fapojuwo, 2005). The operation of the protocol is based on the communication among the cluster head based on multi-hop where the CHs send their data to other CHs until it reaches the sink. The CH selection is based on a random process using cluster splitting algorithm that divides the network into two main clusters and proceeds by dividing the sub-clusters into smaller clusters until the desired number of clusters is achieved. The number of nodes within the clusters are the same. The performance of this protocol shows that the energy consumption is minimised comparing with LEACH and LEACH-C and the network lifetime is improved.

6. Centralised Genetic-Based Clustering (CGC):

To optimise the number of cluster head in the network, a centralised genetic-based clustering protocol for WSN is proposed in (Hatamian, Barati, Movaghar, & Naghizadeh, 2016). In this protocol, the genetic algorithm is used to find the optimum number of cluster heads. The networks are clusters based on a new technique known as onion approach, where the network is divided into several layers to reduce the communications among the cluster head nodes. The results show that the network performance and the lifetime are increased and the packet delivery is significantly improved.

7. Centralised Balance Clustering Routing Protocol:

To make the clustering balanced in the whole network lifetime and suitable with non-uniform distributed nodes, a clustering routing protocol based on a centralised approach is proposed in (Chen, Li, & Kuo, 2013). The aim of this protocol is to balance the clustering through the network operations and this done by designing a systemic clustering algorithm. The clustering formed in a hexagonal shape, and the selection of the cluster head node based on energy and distribution of nodes. The simulation results show that the new protocol improves the network lifetime than LEACH.

To define various points of difference among the available clustering routing protocols, Table (3-1) summaries and review the main points in both distributed and centralised clustering protocols.

Table (3-1) Comparison among Clustering based Routing Protocols in WSN

Protocol	Classification	Basic definition	Advantage	Disadvantage
LEACH	Distributed	- The first protocol in distributed clustering based approach. - The cluster head role is distributed among the nodes. - The clustering approach is based on a random process. - Cluster heads selected first, then, the cluster will be formed (nodes join the nearest cluster head).	- Better than flat protocols in improving the network performance. - The number of clusters are changeable for each round	- The random clustering cause an even distributed of CH role among then nodes. - The clusters may not cover the whole network. - Not suitable in mobile networks. - There is no guarantee to have optimum number of cluster because of the random process. - The round rotation based on time (do not take into account energy level of the nodes).
LEACH-B	Distributed	Enhance LEACH cluster head selection and make the number of cluster heads near the optimum , thus will lead to balancing the energy consumption	- Balanced the system energy consumption and prolonging the network lifetime than LEACH protocol. - taking the node’s residual energy into consideration and keeping the constant and near optimal number of cluster heads at each round	- the random process of the initial round - does not work in the reactive application - add extra overhead for electing CHs
E-LEACH	Distributed	improve CH selection process	The decision of cluster head selection based on nodes energy level	The random process of the first round add an extra overhead

EE- LEACH	Distributed	The formation of the clusters and cluster head selection is based on nodes energy level	Use Gaussian for better node coverage	Lacks of security
EEE-LEACH	Distributed	Based on multi-hops communications to reduces the distance from cluster head to base station	introduces Master Cluster Heads along with Cluster Heads to balance the CHs role	- The probability of select the master CH is effected the protocol performance and should be the optimum value - Location unaware - Random CH selection
PEGASIS	Distributed	Based on chain clustering	To reduce the overhead that occurs in the clustering function and data gathering	- adds a new overhead related to chain shaping - lacks dynamicity
PEGASIS-LEACH	Distributed	Gathering the fundamentals of the LEACH and PEGASIS to improve the energy efficiency	Prolongs the network lifetime and improve dynamicity	- Location unaware -Not suitable for heterogeneous network
TEEN	Distributed	two thresholds sensed attribute, hard and soft threshold, are used to enable the SNs to sense the critical conditions and prevent them from sensing the data continuously, which will reduce the energy consumption.	- Work in critical applications - Suitable for event based applications and real time applications - provides a trade-off between the accuracy and energy consumption	- the threshold values do not reach the SNs, they will stop communication and sensing and will not be used in periodic applications. - Unsuitable for regular data gathering applications. - Work in reactive applications.
APTEEN	Distributed	Combines the charactersitics of both proactive and reactive networks to provide periodic data collection.	Use in Hybrid networks	Its main drawback is in TEEN, which is the extra overhead, and the complexity of clustering function in multi-level.

LEACH-SC	Distributed	A new method is used to choose cluster heads to extend the lifetime of the network.	balanceing the energy consumption among the sensors	Unsutabile in homogenous networks
Narrative-LEACH	Distributed	The cluster formation based on tree where the node in the tree can reach the sink	Based on multi hop scheme to balane the node's energy	The multi hop cause an over head on the nodes near the sink
TL-LEACH	Distributed	Based on the two-level hierarchy to allow for better energy consumption especially in high density networks there are two types of cluster heads, primary and secondary.	Prolongs the network lifetime in high density networks	The random process is not efficient
DL-LEACH	Distributed	Improve the CH selection and balance the energy consumption by using double types of CHs	- Prolong network lifetime - Solves the optimal number of cluster heads based on the network minimum energy consumption	Add an extra over head on the CHs near the sink
Cognitive LEACH	Distributed	Enhanced the cluster head selection by using the ratio of the nodes' current residual energy multiplies by the root square of nodes' neighbours	Improves the performance of the network and increases its lifetime.	- Not suitable for heterogeneous network and multi hopes communications
S-LEACH	Distributed	Utilities from the solar energy powery supply	Had a significant impact on the network behaviour and increased the network lifetime	Sun duration affect the nodes energy level and thus will affect the network lifetime
HEED	Distributed	Use sensors' residual energy and their communication Cost in cluster head selection	Uniform CH distribution	-The clustering performing in each round is the same as in LEACH, and this will cause extra

				energy consumption and affect the network lifetime - Multi-hop communication, this will cause the death of the nodes early
UCR	Distributed	Forms the clsuters with different clsuter size where the CH near the sink will have smaller size than the CH faraway from the sink	Improve the network lifetime in multi hope networks	Low robustness
CEED	Distributed	- Cluster head selection is optimised based on the probability process - Protocol based on multiple systems where only the cluster head nodes near the sink can forward the data	Improves the network lifetime and stability period	The problem of multi hope communications
Unequal Clustering Routing for Mobile Education Protocol	Distributed	The clusters formed based on a circle area with the sink as the centre. These circles area had a various radius in order to balance the energy consumption	- To utilities from the clustering protocol in learning applications -Reduces the energy consumption of cluster reconstruction	-Not suitable if the sink locates outside the sensing area. -Not suitable for heterogeneous networks
DEC	Distributed	The cluster head selection based on a double phase selection scheme	Use in heterogeneous networks	Add extra over head in CH selection

EP-LEACH	Distributed	Use EH-WSN (Energy Harvesting WSN) to improve the network lifetime	Prolong network lifetime	Poor performance in terms of complexity and message overhead.
LEACH-C	Centralised (Sink responsible on clustering function	- First protocol in Centralised clustering based approach. - Centralised version of LEACH to improve the network performance and lifetime. - A list of cluster head will be generated based on nodes energy level and will be fixed during the protocol operation. - Cluster heads selected first, then, the cluster will be formed (nodes join the nearest cluster head).	- Centralised responsibility by the sink improve network management and control - LEACH-C improve the delivery of the packets of LEACH by 40%	- Generate list of CHs nodes, which is unchangeable. - Not suitable in mobile networks. - The round rotation based on time (do not take into account energy level of the nodes).
Modified LEACH-C	Centralised (Sink responsible on clustering function	uses the distance between the CHs and cluster members as well as the distance between cluster members and the sink as the main parameter	improve the cluster head selection process in LEACH-C	Does not take nodes energy level in CH selection process
LEACH-CC	Centralised (Sink responsible on clustering function	Use nodes' energy level in CH selection	enhance the network lifetime	Not suitable for multi hops networks

EELEACH-C	Centralised (Sink responsible on clustering function	Use sort algorithm in CH selection to create the CH list and the node with high energy level will be CH for the current round	Prolong network lifetime	if there are two nodes with the same energy level, the node that will be a cluster head is based on nodes id, which is not an efficient method
BCDCP	Centralised (Sink responsible on clustering function	Based on multi-level CH-to-CH communications and has equal size of clusters	Extend the network lifetime	- The selection of multi CH is randomly - Adding one CH o forward data to sink cause an extra over head on this CH
CGC	Centralised (Sink responsible on clustering function	To optimise the number of cluster head in the network	- Suitable for large-scale network because of using an onion approaches - Improve network lifetime	Not suitable for heterogeneous and multi hope networks
Centralised Balance Clustering Routing Protocol	Centralised (Sink responsible on clustering function	Form the clusters in hexagonal shapes and optimise the cluster head selection	Balancing the energy consumption of the nodes Prolong network lifetime Improve the data transmit effectively	Lacks of scalability Number of nodes in each cluster is the same

3-5 Critical Analysis

As shown from the previous clustering routing protocols in WSN, all the available researches focused on changing either the approach of cluster formation or cluster head selection as a new technique to improve the network lifetime. However, in terms of number of communications, the same procedures had been followed for all available protocols.

The review for the available protocols help to find the appropriate assumptions and properties that can used in the new design in order proposed better protocol and achieve the aim of the research. Therefore, a new centralised and virtualised clustering routing (VCR) protocol had been proposed. The main concept of the new protocol is to minimise the number and amount of communications during the clustering function in both distributed and centralised protocols as well as using efficient techniques in cluster formation, cluster head selection, rotate CH role and cluster re-formations in order to improve network lifetime.

According to this, the general flowchart of the new protocol will be different from distributed and centralised types and it shown in Figure (3-13). The next chapter will introduce the main characteristics and functions for the VCR protocol.

3-6 Summary

In this section, the clustering functions and cluster-based protocol classifications have been reviewed and explained. The most popular type is the distributed where the nodes are responsible for the clustering function. The main problem, which should be managed in distributed clustering protocols, is the communications during the cluster formation and cluster head selection. The first distributed clustering protocol (LEACH), which is the case study of this thesis, as well as various examples of the available distributed clustering based routing protocols, have been discussed and reviewed.

Furthermore, the other protocol type is the centralised protocol. The most important problem in this type is the process of information sending at the beginning of each round to provide the sink with their information.

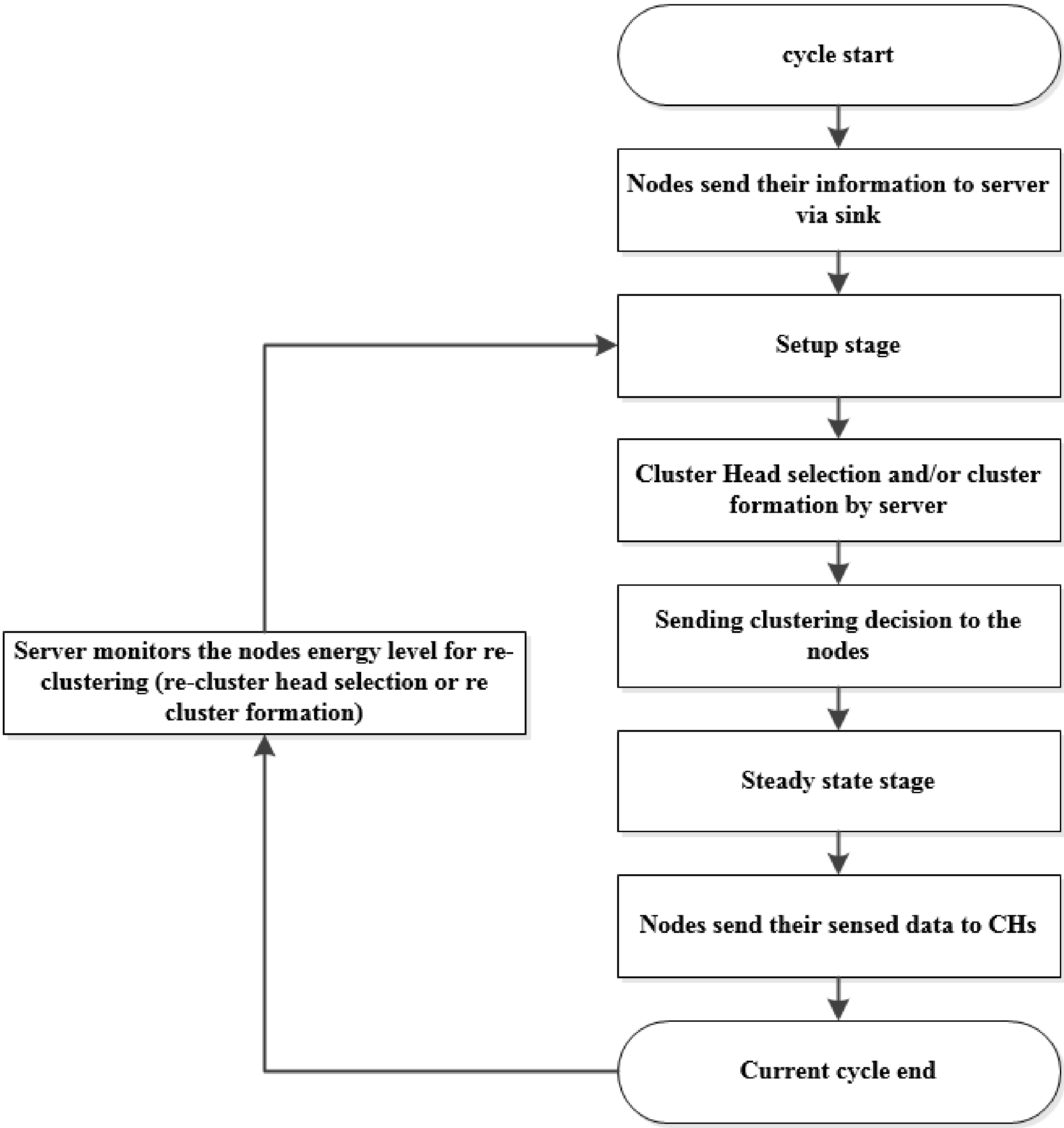


Figure (3-13) Proposed Protocol (VCR) operation flow chart

Chapter Four

The Virtualised Clustering Routing (VCR) Protocol

4-1 Introduction

In this chapter, the principles, functions, and characteristics of the proposed protocol are discussed.

As discussed earlier, the communications (sending and receiving) among the sensor nodes and between them and the sink are the main source of energy dissipation during the operation of clustering function; therefore, to achieve better energy efficiency, these communication activities need to be controlled and minimised. For these reasons, a new virtualised clustering protocol is proposed in this chapter.

4-2 The Assumptions of the VCR Protocol:

In the clustering based routing protocols, the most important issues are how the clusters are formed and which node will be the cluster head to improve the energy efficiency and maximise network lifetime.

In light of this, the following list presents the proprieties and the assumptions that are used during the design of the proposed protocol in order to achieve the design aim and improve network lifetime; Figure (4-1) outlines these features:

- Dynamic cluster formation and cluster head selection: which mean as soon as the clusters formed and/or cluster head selected, they will be not fixed and their rotation will based on certain conditions that will be discussed in details in this chapter.
- Homogenous: all the sensor nodes have the same energy level (at the beginning of the process), processing and storage capabilities. This was selected to balance the roles among all nodes.
- Centralised/Virtualised: the NFV server will be responsible for the majority of the computational activities.
- Non-probabilistic: a more deterministic technique will be used to select the cluster head and form the clusters to achieve energy efficiency and improve network lifetime.
- The sensor nodes have a fixed position after deployment (stationary).
- The sink is in a stationary mode and does not have energy constraints.
- For research purposes, the sink will be initialised with the size of the network (number of nodes in the network).
- The sensor nodes will always have data to send within their time slot.
- Inter and intra-communication will be a single hop.
- The sensor nodes know their IDs, location and initial energy, as well as sink ID and position, and use them during the initial stage.
- The energy consumption of sleep mode is small and has a negligible effect on the overall consumption (Han, Zhang, & Yang, 2008; Liu, Tsui, & Zhang, 2010; Srivastava, 2002).
- The new selection of the cluster head for each cluster can be restarted based on an energy threshold value. When the energy of CH comes down below this value, the NFV server will re-select new a CH (the remaining energy of CH can be found by subtracting its initial energy level from the consumed value).

- Clusters will be formed first, and then the cluster head selection for each cluster will be selected based on a certain cost function.

- The re-clustering process (reform the clusters) will restart when all nodes within the clusters have been selected as cluster head in previous rounds.

- The intra-communications between the CHs and the base station (BS) use a unique code to prevent any packet loss between the CHs and the BS.

- The inter communications between the sensor nodes and their cluster heads are based on Time Division Multiple Access (TDMA) technique that sets a time slot for each node for sensing their data.

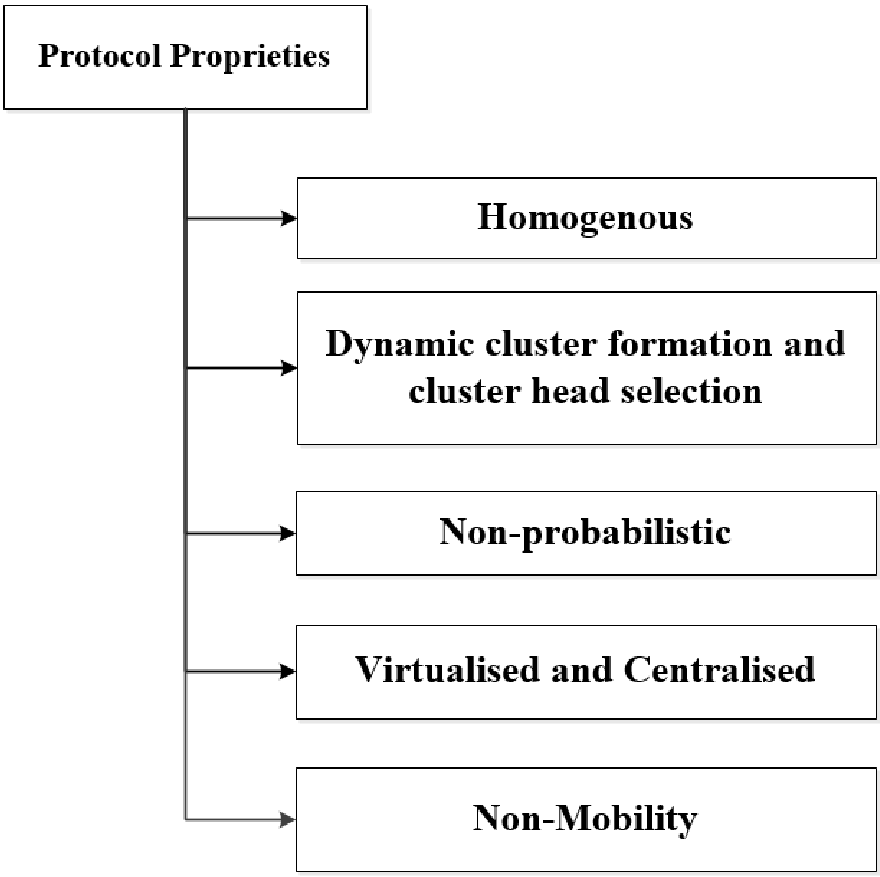


Figure (4-1) Virtual Clustering Routing (VCR) Protocol Proprieties

4-3 VCR Protocol Functions:

The general operation of the VCR protocol divided into various functions as follows, the more details for each function will be explained in the following next sections:

1- Node discovery function: this is the initial stage where the nodes send their information (node ids, energy level and position) to the server via the sink. For research purposes, the sink will be initialised with the size of the network (number of nodes in the network).
2- Calculation Function: After receiving the nodes' information by the server, various calculation process will be done in order to start the clustering function.
3- Clustering function: the clustering step splits into two main stages, setup and steady state. The setup stage contains the cluster formation and cluster head selection functions. The server will manage and control these functions based on certain parameters and will send the result to the nodes. On the other hand, the sensor nodes, after receiving the clustering decision, will start to transmit the sensed data to their cluster head node, which constitutes the steady stage step. To understand the timescale of the cycle, Figure (4-2) represents the timescale for the cycles during the protocol operation. From this figure, it shows that for the next cycles, the timescale will contain clustering decision from the NFV server
4- Energy Consumption calculation Function: after completing the clustering function, the server will estimate the amount of energy consumption using the proposed mathematical model that will explain in the next chapter, in order to manage the network operation and checking if the cluster head should be reselected or the cluster should be reformed.
5- Cluster Head reselection function: this function will be activated when the cluster head node need to be change.

6- Re-Clustering Function: when the re-clustering condition satisfied, this function will be processed. The re-clustering condition is all nodes within the cluster be CH).

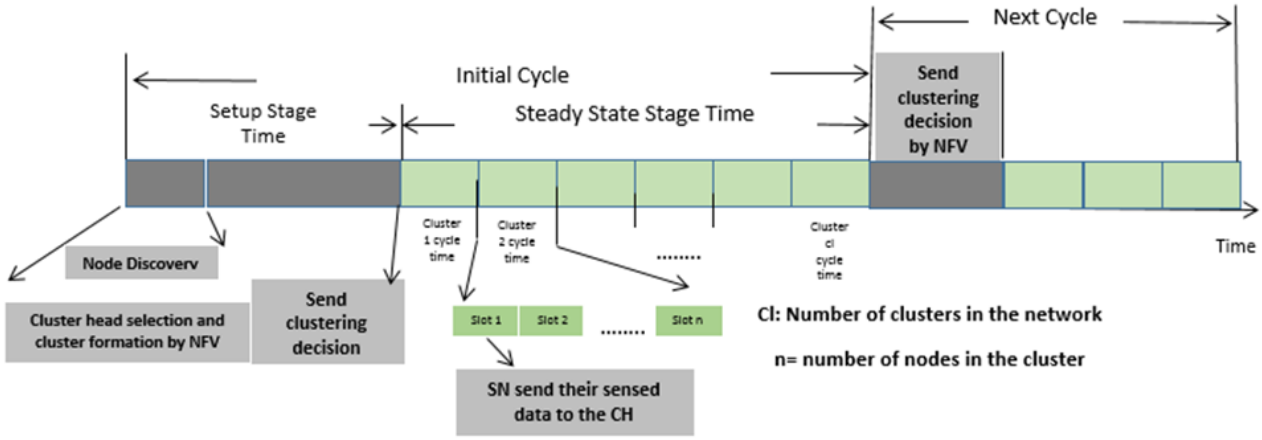


Figure (4-2) VCR Clustering cycle

Figure (4-3) illustrate the general diagram for the protocol functions and the details of each functions will be explained later in this chapter.

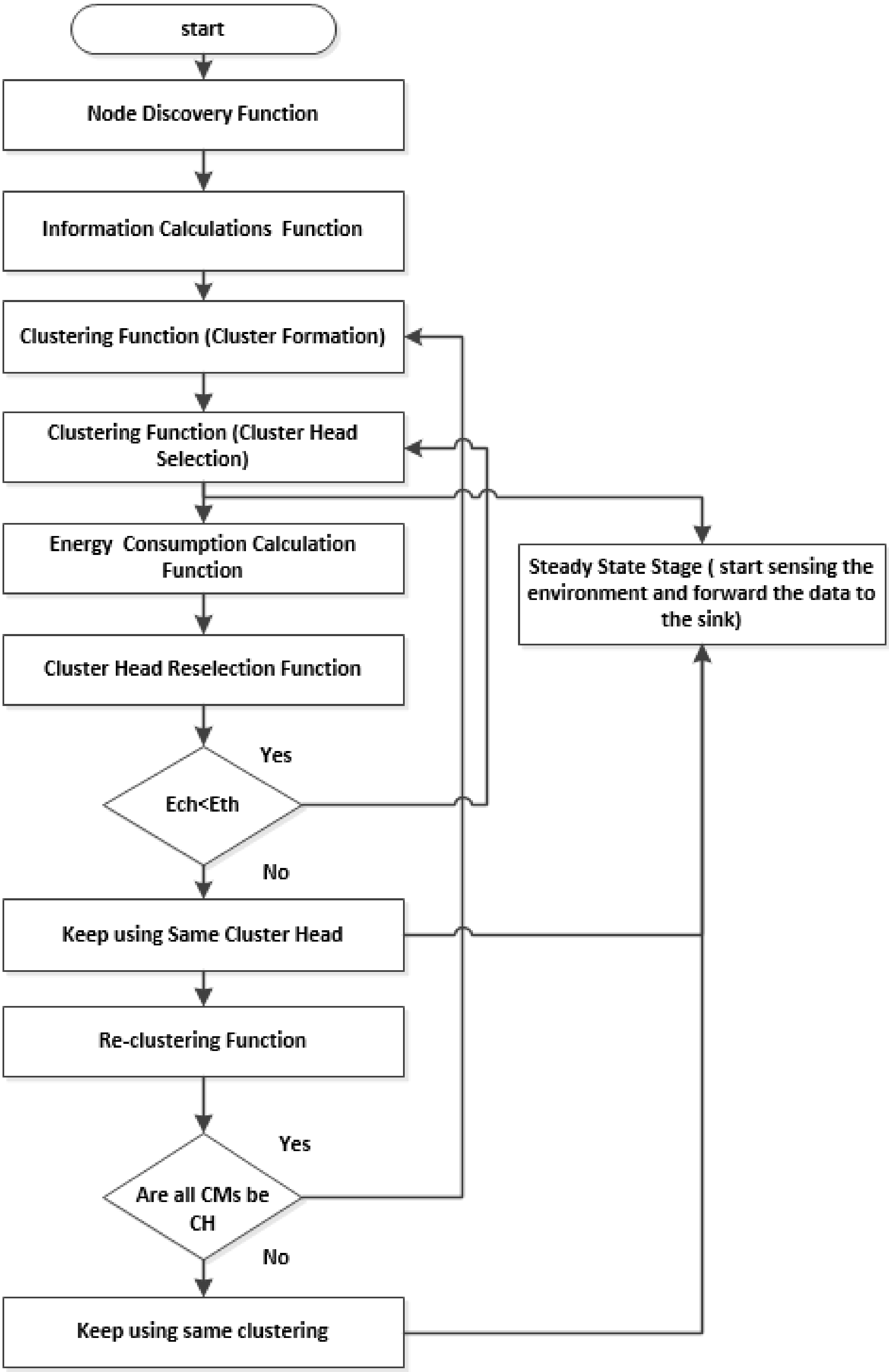


Figure (4-3) VCR Functions

Regarding communications that take place during the operation of the proposed protocol, Figure (4-4) illustrates the number of transmissions and receiving processes in both cases.

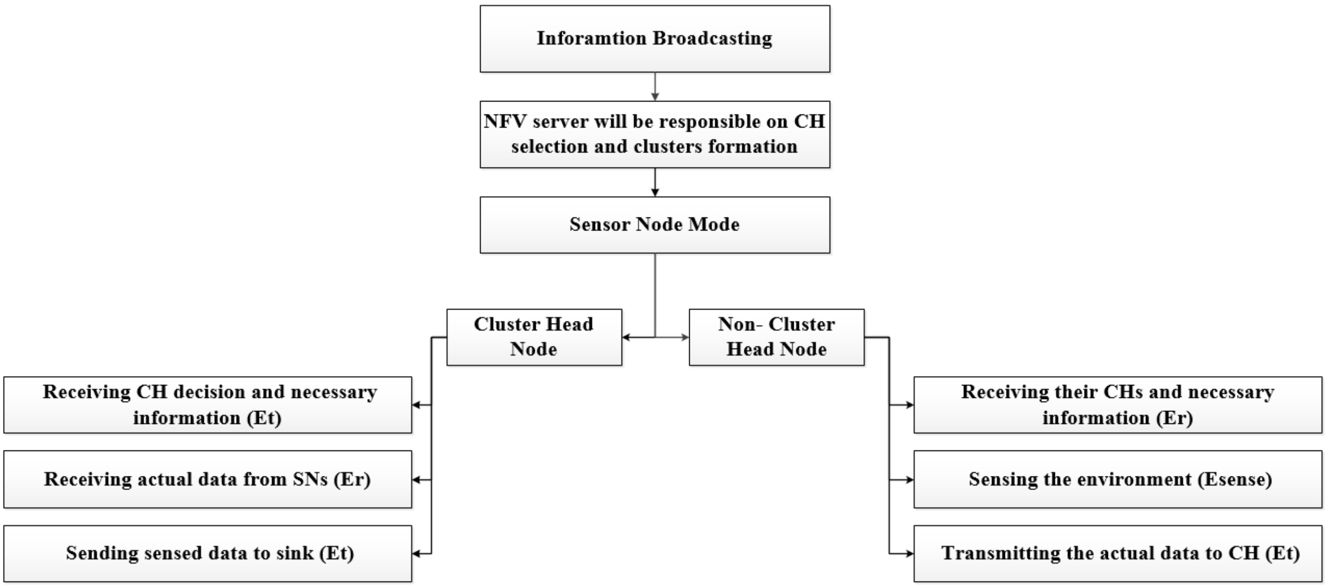


Figure (4-4) VCR Communications Fields

4-3-1 Node Discovery Function

This is the initial stage where the sensor nodes will send their information to the sink that will forward it to the server as in Figure (4-5). As mentioned previously, the sink will initialise with the size of the network (number of nodes in the network).The nodes information will be sent using node discovery packet (SN_Dis_PDU) that shown in Figure (4-6), full details of this PDU is in Appendix A. The sending process occurs at the beginning of the initial round only, and it is not repeated.

The sending process performed just once at the beginning, unlike the existing centralised clustering protocols where the sending occurs at the start of each round.

After that, the sink will forward the infirmation to the server using a Sink to Server Discovery Packet (Sink_Server_Dis_PDU) illustrated in Figure (4-7), full details of this PDU is in Appendix A.

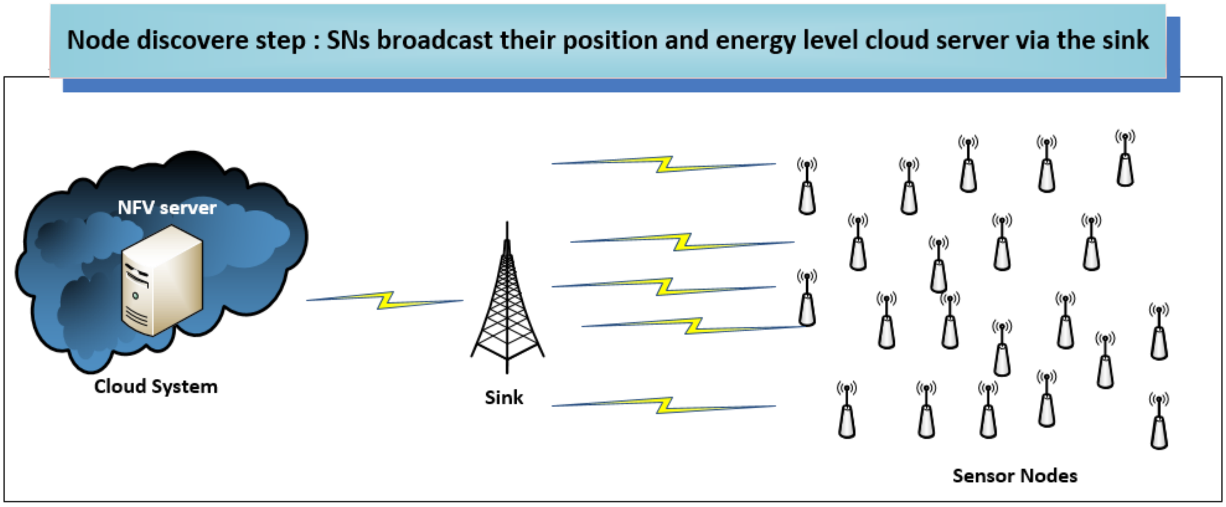


Figure (4-5) Node Discovery Function

ToP (4 bits)	Payload Size (12 bits)	SN ID (2 Bytes)	Data (24 Bytes)

Node Position Latitude (8 Bytes)	Node Position Longitude (8 Bytes)	Energy Level (8 Bytes)

Figure (4-6) Node Discovery Packet (SN_Dis_PDU)

ToP (4 bits)	Payload Size (12 bits)	SN 1 Info (26 Bytes)	SN 2 Info (26 Bytes)	....	SN (n) Info (26 Bytes)

SN ID (2 Bytes)	Node Position Latitude (8 Bytes)	Node Position Longitude (8 Bytes)	Energy Level (8 Bytes)

Figure (4-7) Sink_Server_Discovery Packet (Sink_Server_Dis_PDU)

4-3-2 Information Calculation Function

As mentioned previously, the central server (NFV server) will be responsible for the management of this step. The protocol operation is divided into two stages: the set-up, where the clusters will be formed and the cluster head nodes will be selected; and the steady state (data transmission) where the nodes within the cluster start to send their data according to their time slot.

After receiving the information from the sink, the NFV server starts to perform the necessary calculations to form the clusters and select the cluster head for each one, the calculation process by the NFV is as illustrated in Figure (4-8).

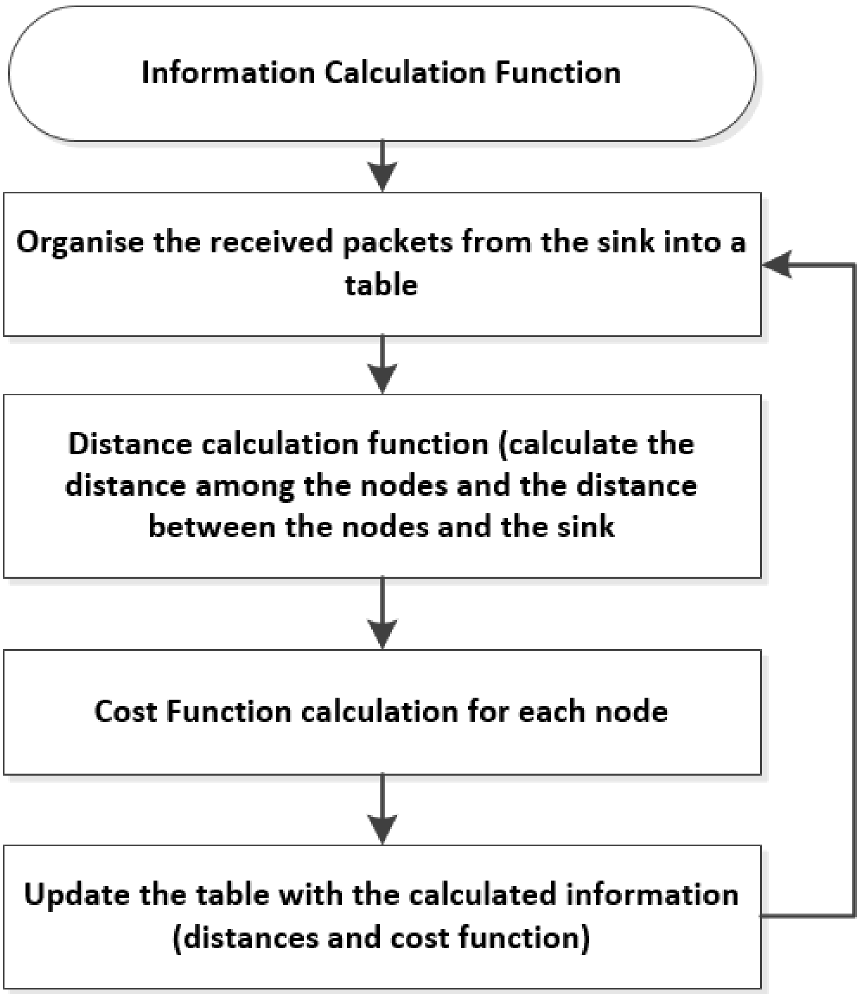


Figure (4-8) Information Calculations Function

The calculation results will be collected in an information table that contents:

1- Node ID
2- Node Position (X and Y coordination)
3- Node's Current Energy Level
4- Node's distance to sink
5- Node's cost function

As mentioned previously, the first calculation process for the server is to calculate the distance between the nodes and the sink and among the nodes themselves and here the Euclidian distance will be used to calculate the distance.

The distance formula between the sensor nodes and the sink is as shown in Equation (4-1). The pseudocode for this step is as in Code (4-1). Then, the server will update the information table with the result from this step.

$$D_{sn\_sink}=\sqrt{(\boldsymbol{x_{sink}}-\boldsymbol{x_{sn}})^2+(\boldsymbol{y_{sink}}-\boldsymbol{y_{sn}})^2} \tag{4-1}$$

Where (x_{sink},y_{sink}, x_{sn}, y_{sn}) represents the sink and sensor nodes coordination.

```
% Generate loops depend on number of nodes in the network
        For i=1 to total number of nodes
        Sink coordination =Sink(x),Sink(y)
        Dis(i,sink)=sqrt((Sink(x),-xi)^2-(Sink(y)-yi)^2
% Form table to store these data
        Table_Node_id (i)= i
        Table_Distance_to_sink)= Dis(i,sink)
        End
```

Code (4-1) Pseudo Code for Distance between Sensor Nodes and the Sink

Another necessary element for cluster formation is the distance between the nodes; therefore, the server will calculate the distance among the nodes using formula (4-2) and store the results in another table that include:

1- Node's ID (i)
2- Node's ID (j)
3- Distance between Node i and Node j

$$D(i,j)= \sqrt{(x_{snj} - x_{sni})^2 + (y_{snj} - y_{sni})^2} \quad (4\text{-}2)$$

Where (x_{sni},x_{snj},y_{sni}, y_{snj}) are the coordinates of the nodes.

The pseudocode for this step is illustrated in Code (4-2).

```
% Generate loops to find distance between each node
        For i=1 to total number of nodes
        For j=1 to total number of nodes
        Dis(i,j)=sqrt((xj-xi)^2-(yj-y1)^2
% Form table to store these data
        Table_Node id (i)= i
        Table_Node id (j)=j
        Table_Distance (i,j)=Dis(i,j)
End
```

Code (4-2) Distance between sensor nodes pseudo code

After this step, the server will update the information table with these new data as described in Pseudocode Code (4-3).

```
For i=1 to total number of nodes

Esn=sensor nodes' initial energy level

Cost(i)=dis(i,sink)/Esn(i)

Table_nodeid=i

Table_SN_Position=Xsn(i) , Ysn(i)

Table_energy=Esn(i)

Table_distancetosink= Dis(i,sink);

Table.cost= Cost(i);
```

Code (4-3) Pseudo Code for Cost Function Calculation

Now, after the general idea and calculation steps have been explained, in the next sections, the details of the clustering function (setup stage and steady state stage) will be explained.

4-3-3 Clustering Function

After completing the necessary calculations, the server will perform the clustering function, as shown in Figure (4-9).

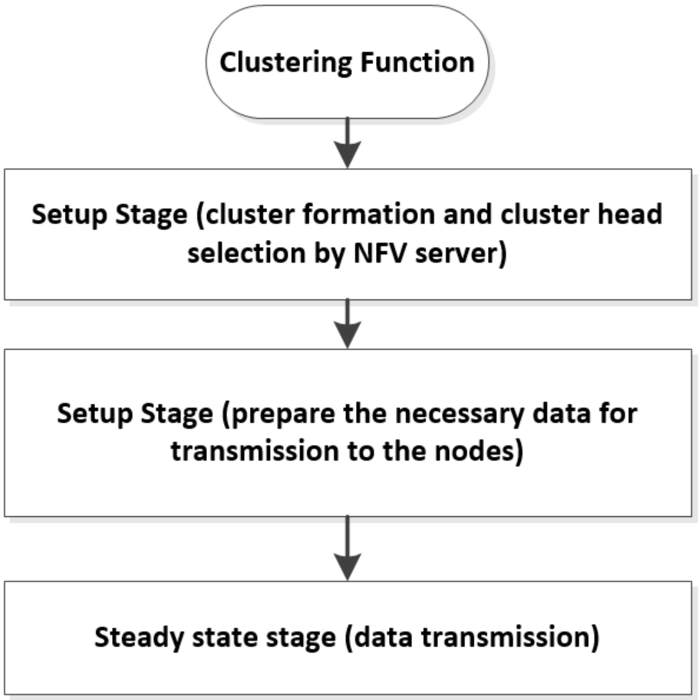


Figure (4-9) Clustering Function

4-3-3-1 Setup Stage (cluster formation and cluster head selection by NFV server)

Step 1- Calculate Optimum number of clusters

Regarding protocol complexity, energy efficiency, scalability and improved network lifetime in the centralised clustering base routing protocols, it is crucial to estimate the number of clusters within the network (Kumar et al., 2014) (Amini, Vahdatpour, Xu, Gerla, & Sarrafzadeh, 2012).

The aim of finding the optimum number of clusters in the network is to balance the energy consumption in the network. The overall energy consumption in clustering depends on the optimum number of the clusters in the network, the number of sensor nodes within each cluster and the cluster head selection (Kumar et al., 2014).

However, the node density, base station position and single/multi-hop communication have a significant effect on the cluster numbers at the network level. In addition to this, the optimum number of clusters is based on different parameters such as the distance between the cluster head and the sink (Kumar et al., 2014).

Therefore, in this thesis and to calculate the expected number of clusters that can be used in the network, Equation (4-3) proposed in (Heinzelman, 2002) will be employed. This equation is based on the network area, sensor nodes and the distance to the sink (d_{min}, d_{max}), and all these parameters are critical to estimate the range of clusters during the protocol design.

$$\boldsymbol{C} = \sqrt[2]{\frac{N.\varepsilon_{fs}.M^2}{2\pi.\varepsilon_{amp}.d_{toBs}^4}} \tag{4-3}$$

Where C is the number of clusters in the network

N represents the number of sensor nodes that are deployed in area M*M,

d_{toBS} ($d_{min} < d_{toBs} < d_{max}$) is the distance between the sink and the sensor node

ε_{fs} and ε_{amp} are constant values and represent the energy consumption in power amplifier in free space mode and multipath fading model.

The result from this equation will be verified using the simulation in chapter six. For each value, the simulation will be executed with different topologies to test the performance of the protocol for each number of clusters and to find the optimum number of clusters regarding minimum energy consumption per cycle.

Step 2- Cluster Formation

Data clustering has vital importance in the data mining system; the idea is to divide the set of data intro groups based on different features such as groups of the same colour or data type. As mentioned previously, the most popular algorithm in this field, which is the k-means algorithm, will be used in the protocol design (MacQueen, 1967).

K-means clustering algorithm is one of the simplest learning algorithms that solve the well-known clustering problem, the most important factor for this algorithm is the availability of a required number of clusters, and after finding how many clusters are needed, the nodes will be set intro clusters. The initial steps of this algorithm are to assign nodes known as centroid nodes according to a number of required clusters (Bora & Gupta, 2014).

The distance matrix plays a major role in the reduction of the energy consumption during the clustering process. Therefore, partitioning of k-means is based on minimising the squared distance among the nodes in each cluster, which will minimise the communication cost and improve network lifetime.

Choosing certain clustering algorithms is based on the type of data to be clustered and the aim of the clustering. The clustering algorithms are classified into two main types, hard and soft clustering. K-means is one of the hard clustering techniques, which is used in the systems that require exclusive clustering (the data do not share among the clusters).

The general steps of K-means that are used during the research are shown in Figure (4-10) and the details are as described below (Leskovec, Rajaraman, & Ullman, 2014).

1- Initialization step:

- The first initial Centroid Node (CN) will be assigned randomly from the set of nodes, as shown in Figure (4-10a, b).
- From Figure (4-10c), the other CNs (based on required clusters, for example two clusters) will be selected based on distance condition; in other words, the other initial CNs are the nodes that have a minimum distance from the set of maximum distance to other nodes in the network.

2- Classification step:

The other nodes will join the nearest CN (Min (d) minimum distance to it) and the distance is calculated based on Euclidian distances (d).

3- Centroid recalculation:

Reassign new CNs using the formula (4-4) for each cluster and repeat step 2, as illustrate in Figure (4-10d).

$$\text{New CN (x,y)}= \sum \frac{\boldsymbol{x}}{\boldsymbol{n}}, \frac{\boldsymbol{y}}{\boldsymbol{n}} \qquad (4\text{-}4)$$

Where x, y are the coordination of the nodes within the cluster and n is the number of the nodes with the cluster.

4- Convergence condition:

The operation of the K-means will stop when the convergence occurs. Convergence means the centroid node CN does not change, or cluster will not be changed as shown in Figure (4-10 e, f).

In K-means algorithm, the convergence iterations cannot based on random or fixed iterations because it depends on the required number of clusters and number of nodes in the network. Therefore, in this thesis, as will show in chapter Six, the simulation of the K-means will explain how these iterations are changeable.

5- Clusters Information:

The clusters table will be formed. This table contains the clusters members' information such as Cluster ID, Total Number of nodes in the cluster, Cluster members ID, Cluster members' position and Cost function of cluster members.

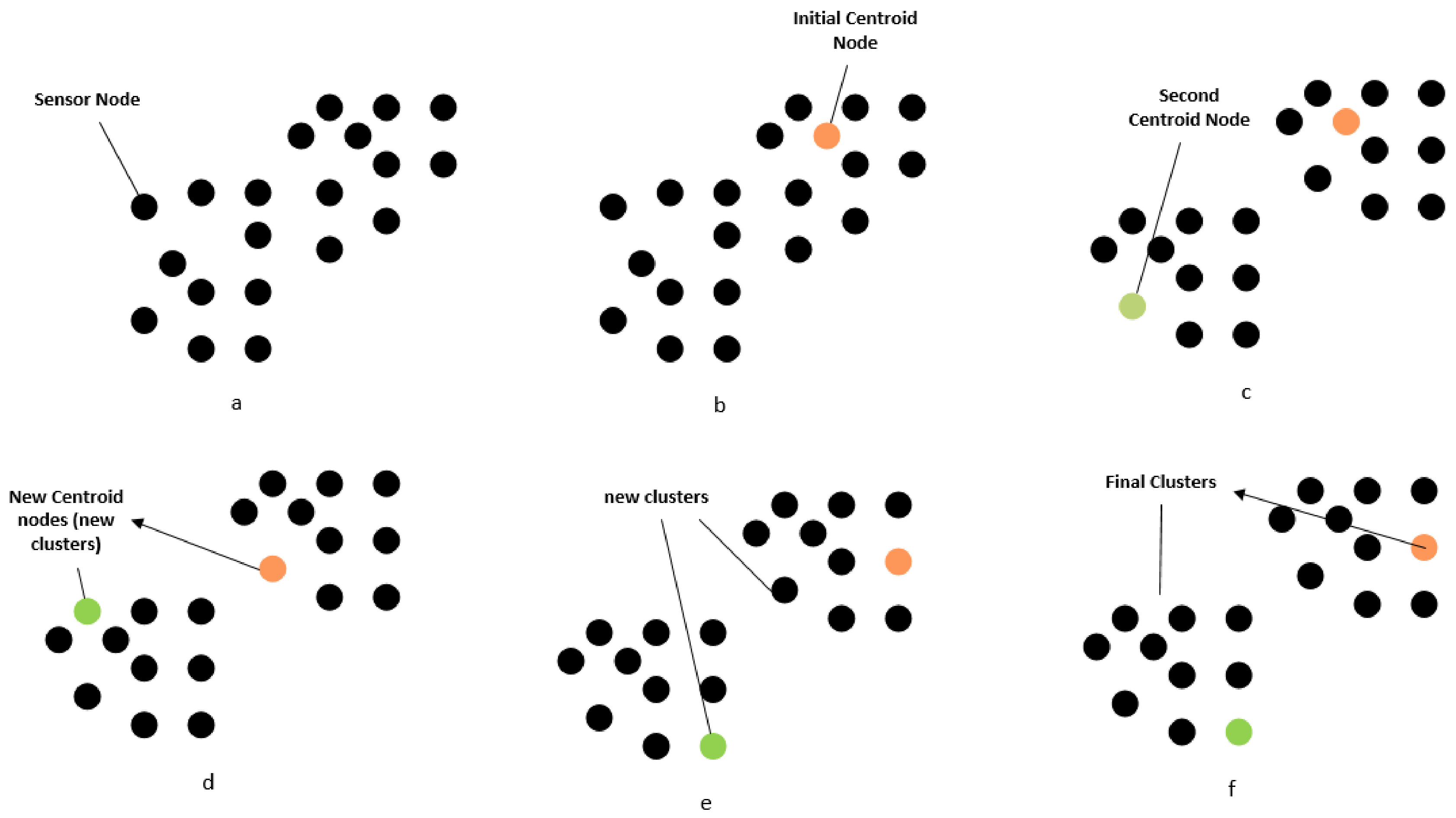


Figure (4-10) K-means algorithm (example if number of required clusters in two)

(a) nodes set (b) first initial CN randomly (c) another CN is node is the furthest node (d) reassign new CN (e) new clusters (f) final cluster

The general flow chart for cluster formation step illustrated in Figure (4-11).

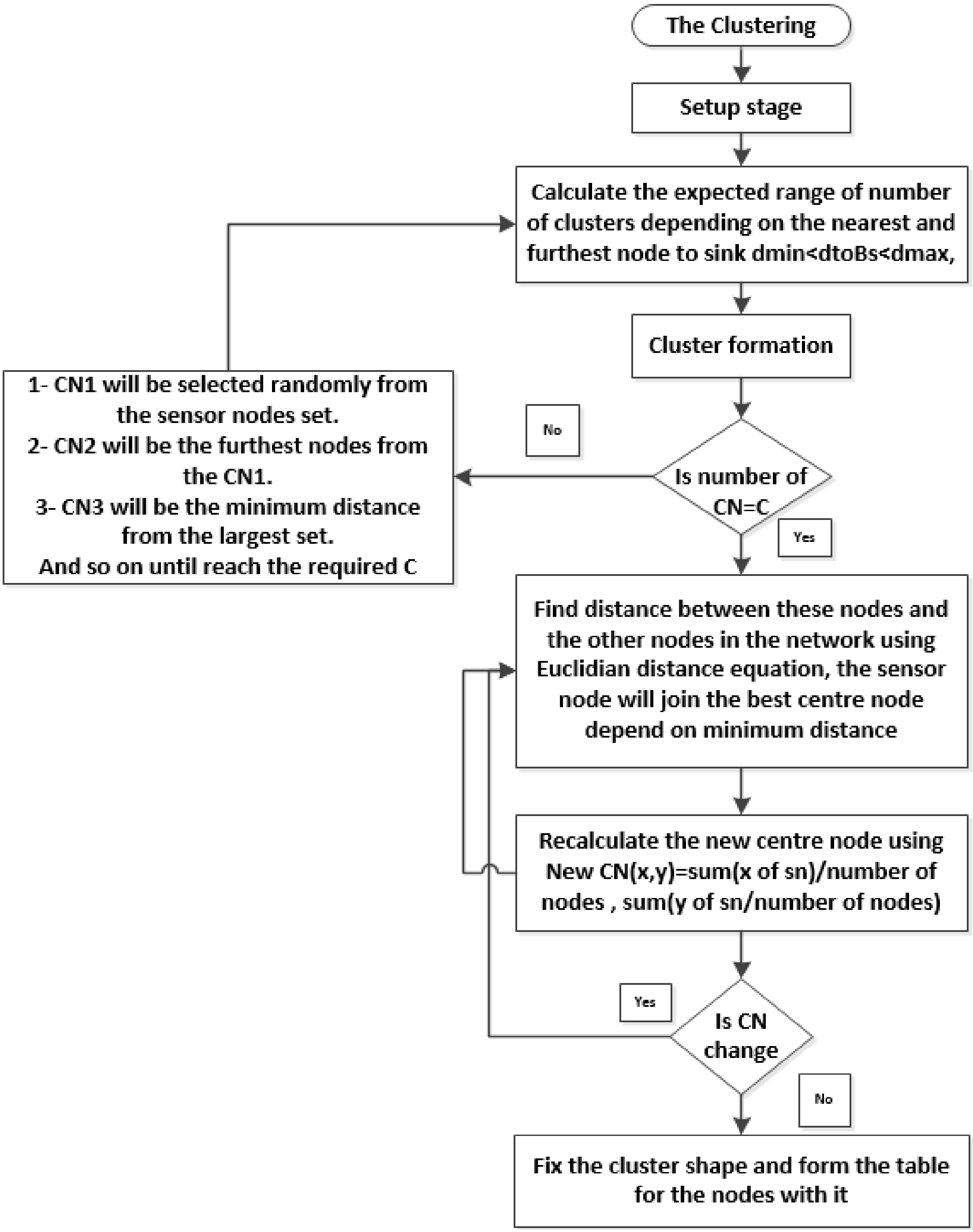


Figure (4-11) Cluster Formation Diagram

After completing the cluster formation, the cluster head node for each node will be selected. The full details are in the next section.

Step 3- Cluster Head Selection

As mentioned previously, the cluster head node will be chosen depending on the minimum cost function and can not be random or based on fixed value of any selected parameters.

Wherefore, the important parameters that affect the energy consumption is the node's distance to the sink and the node's distance with other nodes as well as the current energy level of the node. It is not an efficient way to depend on the distance only because it may be that the node is near the sink, but it has a low level of energy, or it has a high energy level but is far from the sink. In addition, it is not efficient to consider initial energy level of the node. Therefore, the nodes' energy level should be updated after each cycle.

Therefore, the cost function has two main parameters: the distance between the node and the sink ($\mathrm{d_{sntosink}}$) and the current node's energy level ($\mathrm{E_{sn}}$), and the cost function formula is as described in Equation (4-5).

$$\boldsymbol{f(CH)} = \frac{\boldsymbol{d_{sntosink}}}{\boldsymbol{E_{sn}}} \qquad (4\text{-}5)$$

According to this equation, the node with the optimum balancing between distance to the sink and the maximum level of energy will be a cluster head for this cluster and round. The general pseudocode is as shown in Code (4-4).

```
Input – cluster table
Compare cost_function_field
For i=1 to m (number of nodes in the cluster)
Is SN(i)_cost_function=minimum (cost function)
Set SN(i) as cluster head for this cycle
```

Code (4-4) Cluster head selection code

A cluster head table will be formed containing:

1- Cluster number
2- CH ID
3- CH position
4- CH distance to sink

4-3-3-2 Setup Stage (prepare the necessary data for transmission to the nodes)

Once the optimum number of clusters and their members are found, the server will send a Server to Sink Cluster Information Packet (Cl_Inf_Server_sink_PDU) to the sink, as shown in Figure (4-12). This packet contain the full information for the clustering. Description of this packet's fields is found in Appendix A.

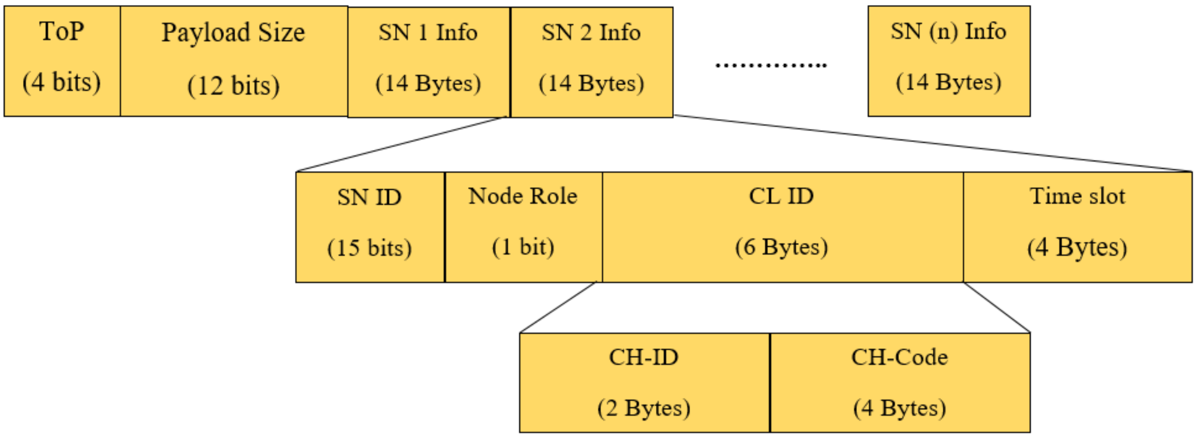


Figure (4-12) Server to Sink Cluster Information Packet (Cl_Inf_Server_sink_PDU)

The sink in turn and after receiving this packet, will send it to the nodes using a Sink to Node Cluster Information Packet (Cl_Inf_Sink_Node_PDU) as in Figure (4-13). Description of this packet's fields found in Appendix A

After receiving the clustering information, if the node role is as CH, it will be in on mode, while if it is as cluster member, it will turn off and waiting for their time slot to transmit the data.

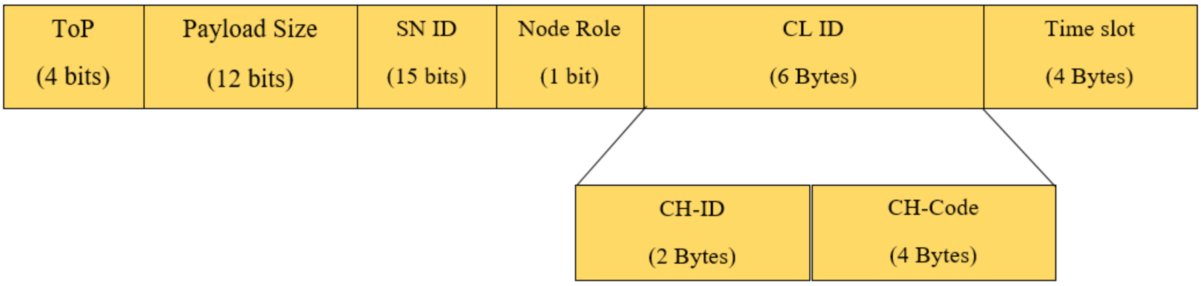


Figure (4-13) Sink to Node Cluster Information Packet (Cl_Inf_Sink_Node_PDU)

4-3-3-3 Steady State stage (data transmission)

In this stage, the sensor nodes will start their sensing activity and transmit the sensed data to cluster head nodes once per cycle according to a certain time slot defined by the NFV server. The cycle numbers depend on the number of clusters in the network. However, the cycle time depends on the number of sensor nodes within the cluster. For each cycle, the cluster head node will send its data at the end of the cycle, the sensed data Info (Sense_Data_Info) shown in Figure (4-14) and the full details is in Appendix A.

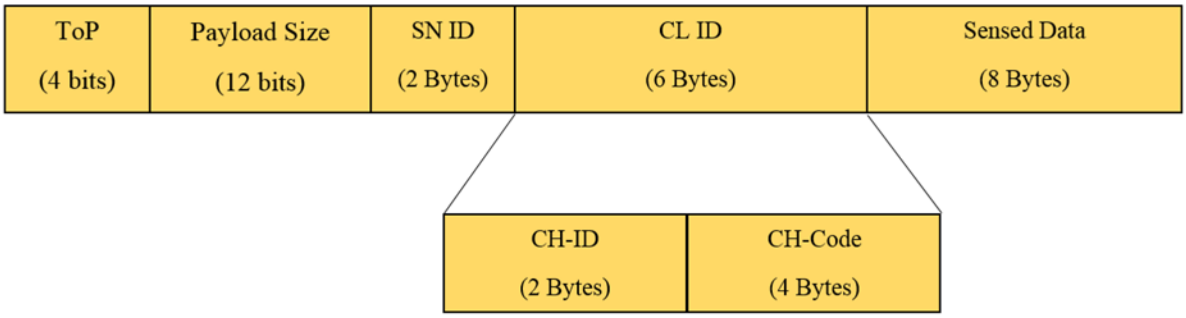


Figure (4-14) Sensed Data Info (Sense_Data_Info)

Once all sensed data from the sensor nodes in the cluster have been received, and before transmission process to the sink, the cluster head performs data aggregation on the data and reduces the amount of raw data that needs to be transmit to the sink. The aggregated data packet (Agg_Data_Info) illustrated in Figure (4-15) and the full details is in Appendix A.

ToP (4 bits)	Payload Size (12 bits)	CH-ID (2 Bytes)	CH-Code (4 Bytes)	Aggregated Data (8 Bytes)

Figure (4-15) Aggregated data Info (Agg_Data_Info)

Figure (4-16) shows the general steps for this stage.

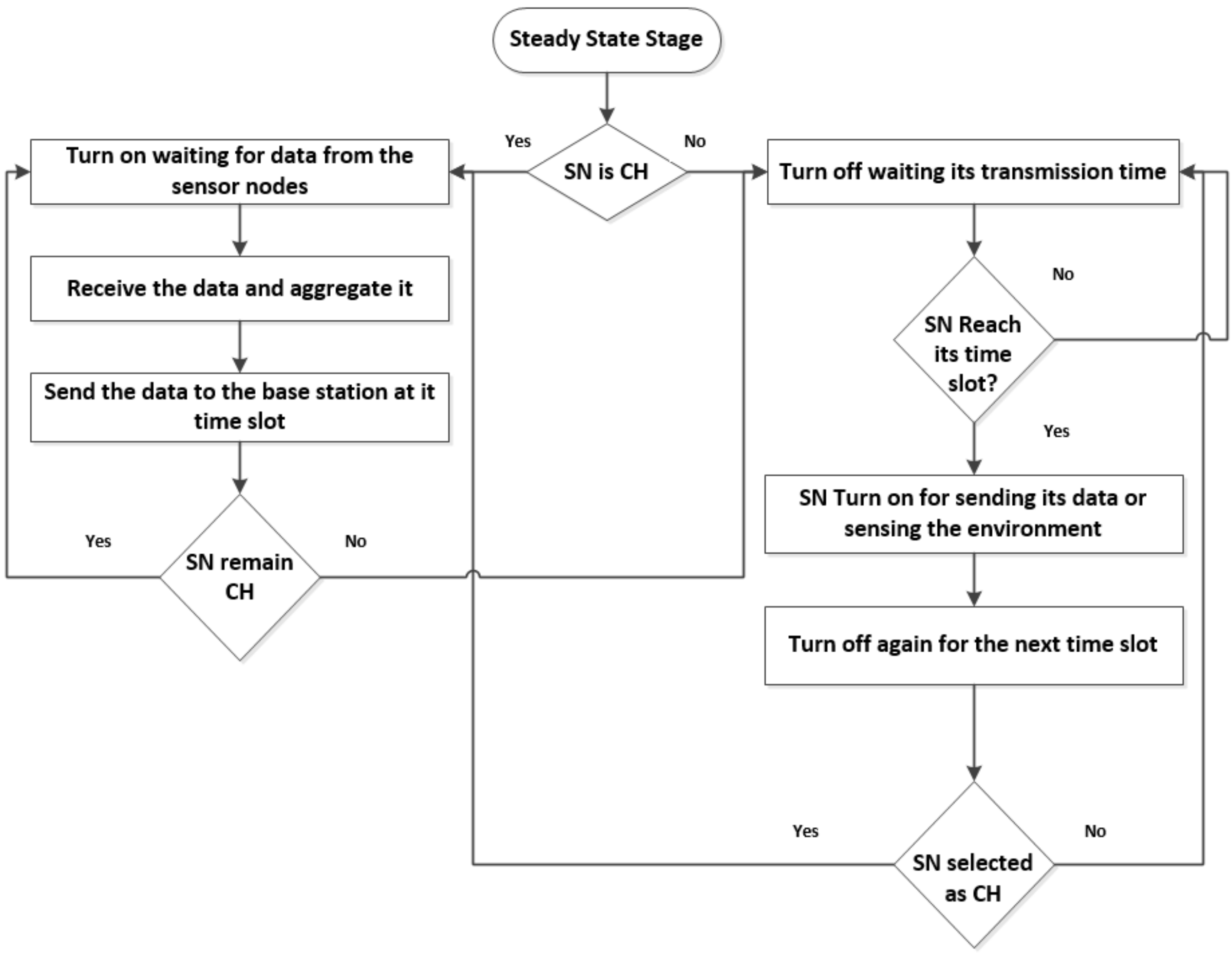


Figure (4-16) Steady state stage

4-3-4 Schedule Formation

After selecting the cluster head nodes and specifying the nodes for each cluster, the NFV server will create a TDMA schedule that is based on the number of nodes within the cluster. The schedule will be used to inform the nodes when they should send their data to the cluster head node. In addition, the same process will be done for cluster head nodes, and the NFV server will form a schedule table for cluster head nodes to know their transmission time to the base station. This process will lead to reduce the number of collisions in the network.

Furthermore, to help the non-cluster nodes to distinguish their cluster head and reduce the amount of interference between the clusters, a unique code will be assigned to each head node by the server, and the non-cluster nodes will use this code during the data transmission to their corresponding head node. Furthermore, the cluster head node will use this code during the communication with the sink.

The sink will send End Cycle Notification Packet (End_Cycle_notify_PDU)to inform the server the end time for the current cycle. This packet shown in figure (4-17) and full details of this packet is in Appendix A.

ToP (4 bits)	Payload Size (12 bits)	Cycle ID (2 Bytes)

Figure (4-17) Notification Packet (Notification_PDU)

4-4 Energy Consumption Calculation Function

After completing the cluster formation and cluster head selection, and the clustering details have been sent to the nodes, the server starts to monitor and manage the networks by estimating the amount of energy consumption ($E_{consumed}$) based on the developed mathematical model. The details of the estimation model will be explained in chapter five.

The current energy level of the cluster head node will be checked to find whether it should be changed or not for the current cycle. The current energy level of the node ($E_{current}$) will be found by the Equation (4-6)

$$E_{current} = E_{Previous} - E_{consumed} \tag{4-6}$$

Where $E_{Previous}$ is the energy level of the node

The values of $E_{current}$, $E_{Previous}$ and $E_{consumed}$ will be organised in an energy table that will be updated at each cycle. The contains of energy table are:

1- Node's ID
2- Node's current energy level
3- Node's energy consumption in current cycle
4- Node's energy level from previous cycle

As mentioned previously, it is important to find the optimum number of clusters within the network during the protocol operation. Therefore, the energy consumption/cycle will be calculated with the different value of C and different network topologies to find the optimum number of clusters in the network based on minimum energy consumption.

4-5 Cluster Head re-selection Function

According to the assumption in this thesis, the time for the node to be a cluster head is not fixed and different from cluster to cluster because it depends on the number of nodes in the cluster, transmission bit rate, and the data packet size.

Most of the previous studies in the clustering technique were based on a fixed time for the re-cluster head selection or re-clustering processes. The round time calculation in these studies depend on the initial number of nodes and then make it fixed for the whole network operation. However, this approach is inefficient because of the nature of the sensor network, which is dynamic, meaning the number of nodes may be changed. Therefore, fixing the round time leads to unbalancing the network load and this will affect its performance.

The server will monitor the energy level of the current cluster head node and check it at the end of each cycle to avoid draining the cluster head energy as shown in Figure (4-18). The new cycle for each cluster will be started under certain conditions, which is based on a triggered process; this means that there will be an energy level threshold, as illustrated in equation (4-7)

$$E_{\text{threshold}} = {E_{avg}}/{2} \qquad (4\text{-}7)$$

Where: E_{avg} represents the average of the sensor nodes' current energy level in the cluster.

It is important to know that the cluster head selection process is distributed among all nodes, which means that the node that will be selected as the cluster head for the current round will be eliminated and not chosen as the cluster head for any new cycle.

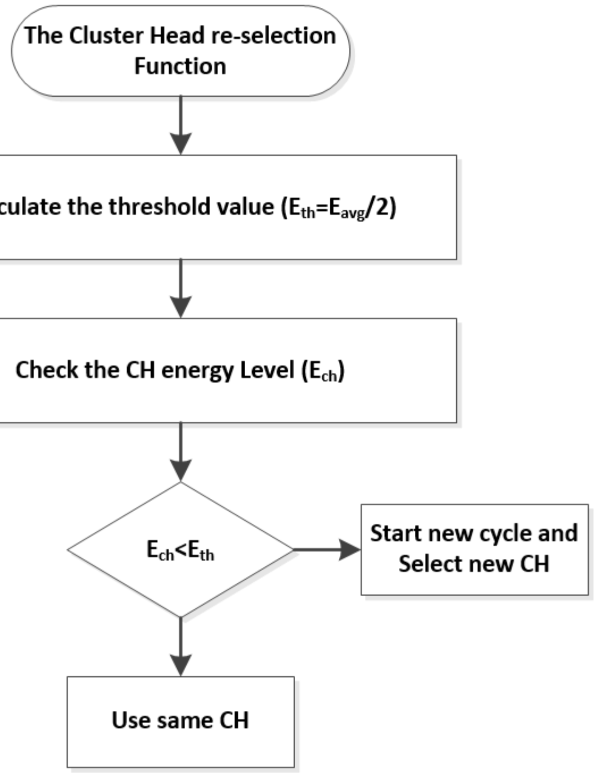


Figure (4-18) Cluster Head re-selection Function

The server will send a Server to Sink Cluster Head re-selection Packet (Reslect_CH_Server_Sink_Packet) , that shown in figure (4-19), contain the information for the new cluster heads for the clusters that should change it CH.

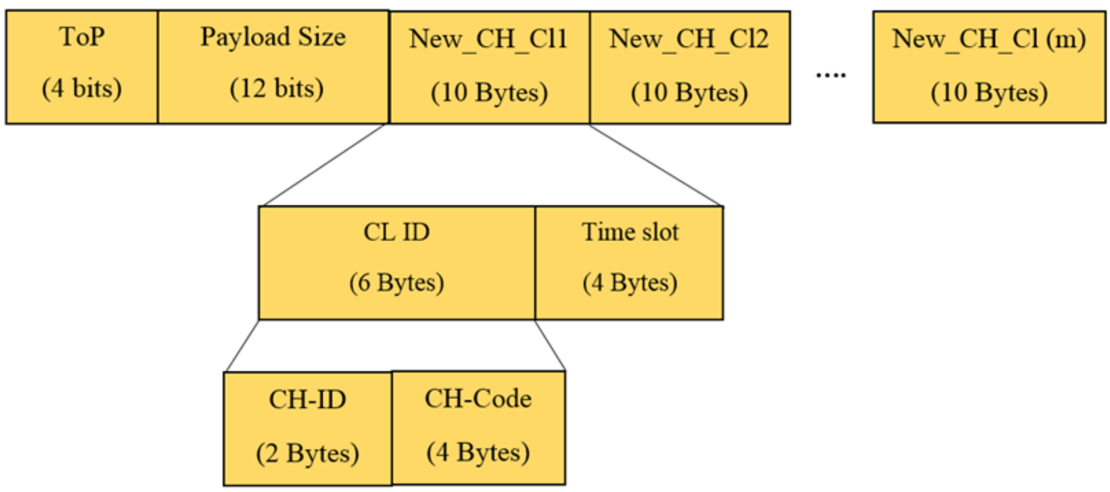


Figure (4-19) Cluster Head re-selection Packet (Reslect_CH_Packet)

The sink will forward this packet using a Sink to Node Cluster Head re-selection Packet (Reselect_CH_Sink_Node_PDU), shown in Figure (4-20), to the nodes. Full details of these packets is in Appendix A.

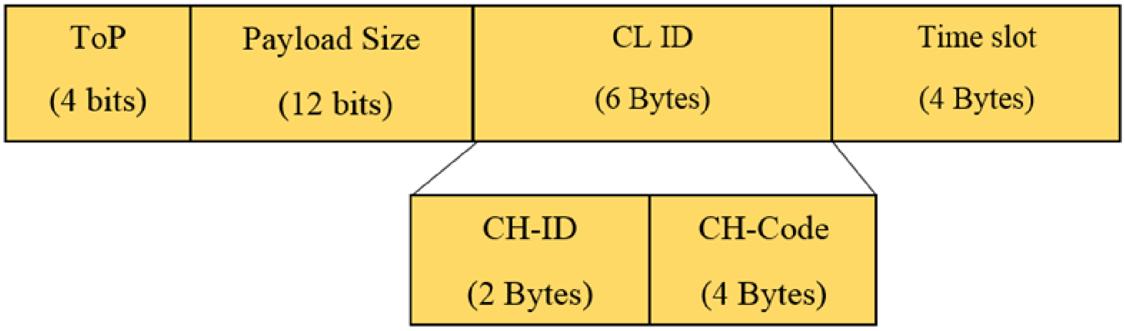


Figure (4-20) Cluster Head re-selection Packet (Reslect_CH_Sink_Node_Packet)

4-6 Re-Clustering Function

Finally, managing the re-clustering process affects the network lifetime, and therefore, it is essential to know when the clusters should be reformed. For the proposed protocol, the re-clustering process will be initiated again when all sensor nodes within the cluster have been elected as a cluster head. As mentioned previously, the new energy level for the nodes will be calculated by the server based on the proposed mathematical model that will be explained in the next chapter. The activity diagram for this function is shown in Figure (4-21).

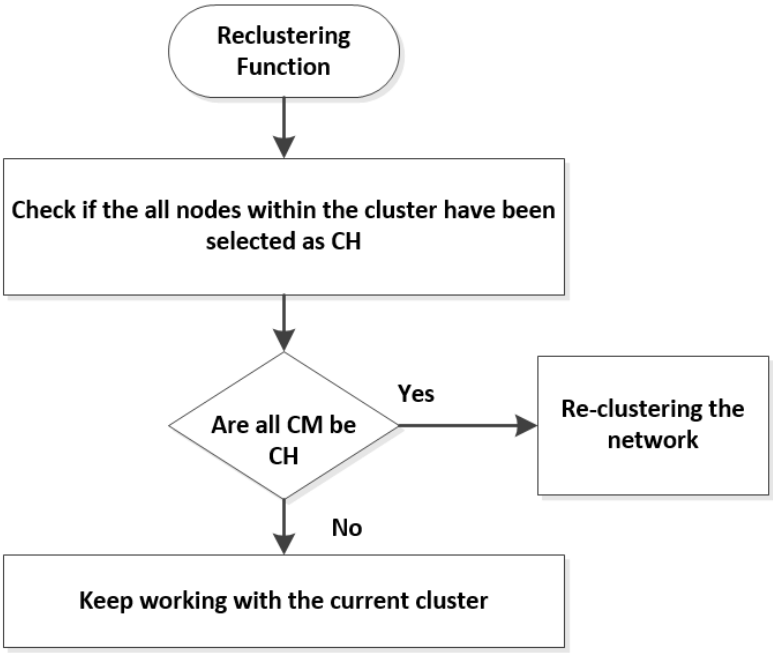


Figure (4-21) Re-Clustering Function

4-7 Summary:

The PDU protocol diagram and the overall flow chart for the VCR protocol description are illustrated in Appendix B and C respectifly.

The general steps of the proposed protocol have been explained in detail in this chapter. A full flow chart had been drawn to explain the general behaviour of the protocol.

The new protocol (VCR) differs from other clustering based routing protocols in the clustering formation process that occurs before other steps, while in other protocols, the cluster formation is done before the cluster head selection.

In clustering, centralised clustering is more efficient than distributed clustering, so it is crucial to determine the optimum number of clusters and which node will be selected as a cluster head to minimise the protocol complexity and improve energy efficiency.

The optimum number of clusters is found based on an optimisation process, which is the amount of energy consumption per cycle. Also, it improves the clustering process by adopted the idea of the k-means (clustering algorithm).

It is also noted that the selection of the cluster head is not random; it depends on a cost function that combines the distance of the node to sink and its current energy level. This is more efficient than just using the distance nodes because it is possible that the node is near the sink but has a low level of energy, or it has a high energy level but is far from the sink. Therefore, the nodes with a minimum cost function, which implies the best balancing between distance to sink and maximum energy level, will be a cluster head.

The rotation of cluster head role (reselect CH) will be a process trigged by an energy threshold, and this will improve the network's overall lifetime by increasing the time for the node to be CH and distributing the selection among the nodes. The next chapter will present the developed mathematical model of the proposed protocol.

Chapter Five

Estimating the Energy Consumption in the VCR Protocol

5-1 Introduction

According to the description of the protocol in the previous chapter, the server is responsible to manage and monitor the network's behaviour during its operation. This chapter introduces the formulation of the energy estimation process that is used by the server to estimate the energy consumed during the operation of the network. These values will be employed by the central server to monitor and manage the cluster head selection and cluster formation.

5-2 Radio Energy Model

The first order radio model (Heinzelman et al., 2000) is used to calculate the energy dissipation during the transmission and receiving, as shown in Figure (5-1).

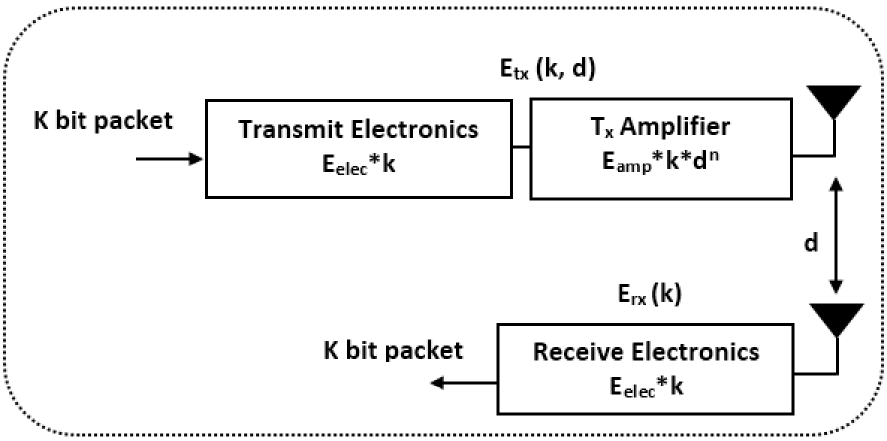


Figure (5-1) Radio Energy Consumption Model (redrawn from (Heinzelman, Chandrakasan, & Balakrishnan, 2000))

From the above figure, the power attenuation depends on the distance between the transmitter and receiver. The distance parameter (d^n) is based on the channel path loss, which is either free space (d^2) used for the short distance communication or multi fade path (d^4) that is used for long distance communication.

Accordingly, the formula for sending a k-bit data to a distance d is

$$E_t = E_{elec} * k + \varepsilon_{amp} \left(\varepsilon_{fs}\right) * k * d^n \quad (5\text{-}1)$$

While the formula for receiving a k-bit data is

$$E_r = E_{elec} * k \quad (5\text{-}2)$$

Where

E_t= energy consumption formula to transmit k-bit data to a d distance,

E_r=energy consumption formula to receive a k-bit data,

k= packet size (bit),

d^n= distance between two sensor nodes or sensor node and the sink,

n is the path loss exponent, which is specified by the radio propagation model (n=2 in free space model and $d<d_0$ (between sensor nodes and cluster head) or n=4 in two ground model and $d>=d_0$ (between cluster head node and the sink), depending on the distance between sender and receiver),

E_{elec}= transmitter and receiver electronics = 50 nJ/bit,

ε_{fs} = energy consumption in power amplifier in free space mode, used if $d<d_o$ = 10 pJ/bit/m^2 (if n=2),

ε_{amp}= energy consumption in power amplifier in multi path fading, used if $d>d_o$= 0.0013 pJ/bit/m^4 (if n=4), d_o=87.7 m ($\sqrt{\frac{\varepsilon fs}{\varepsilon_{amp}}}$ (Wendi Beth Heinzelman, 2002) (Heinzelman et al., 2002).

5-3 Analysis of the Energy Consumption of the VCR Protocol

As discussed previously in Chapter two, the sensor node consumes its energy to perform different types of activity such as processing, sensing and communications. In the communications domain, the node may be in four different modes: transmit mode, receive mode, idle mode and sleep mode. On the other hand, the node modes during the processing are on, off and idle, while in sensing, the nodes can be either in on mode or off mode.

According to this, the mathematical model of the proposed protocol will take into consideration all these fields and activities during the design process. In order to understand the main contents of the mathematical model, Figure (5-2) illustrates the general map for energy consumption fields, which (a) is for cluster head mode and (b) for non-cluster head mode. The general Equations for the nodes in either cluster head mode or cluster member mode is illustrated in Equations (5-3) and (5-4) respectively.

For cluster head mode

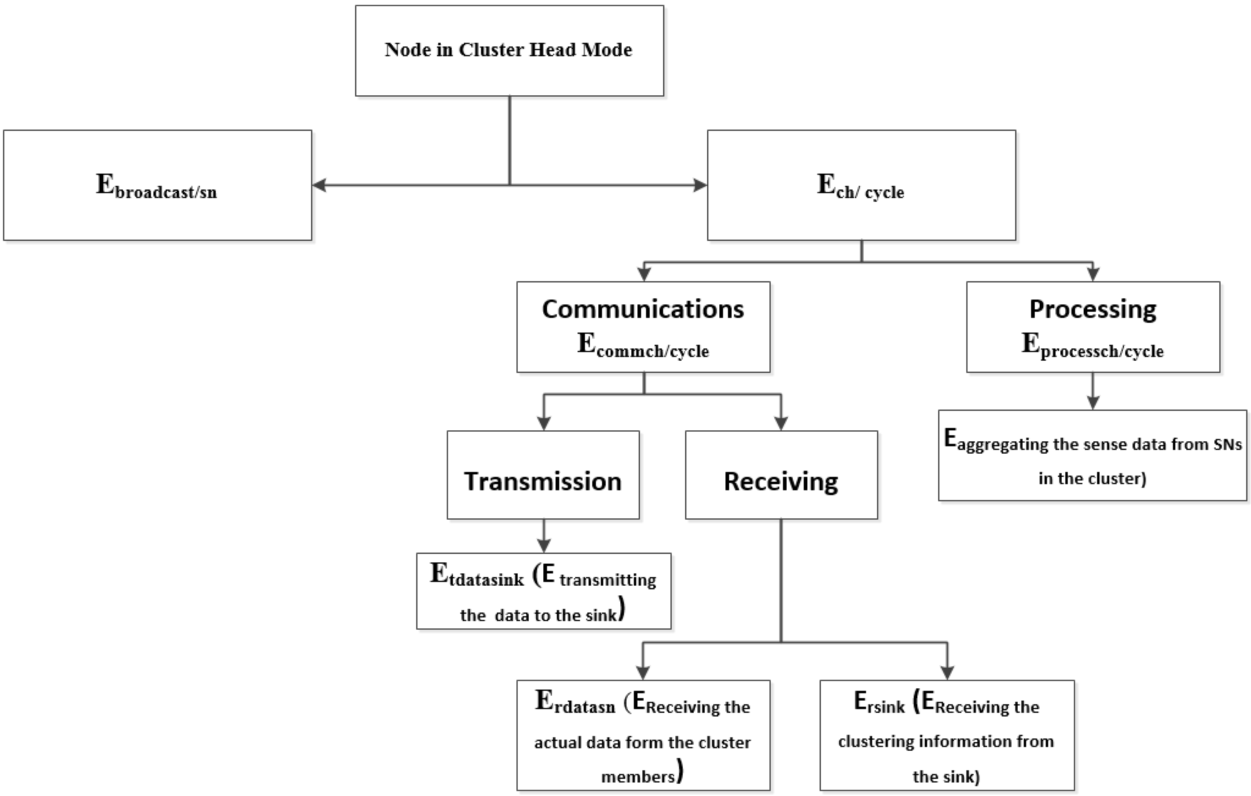
$$E_{total/ch/\,cycle} = E_{ch/\,cycle} + E_{broadcast/sn} \qquad (5\text{-}3)$$

Where $E_{ch/\,cycle}$ is the cluster head mode energy consumption and $E_{broadcast/sn}$ is the broadcasting energy consumption.

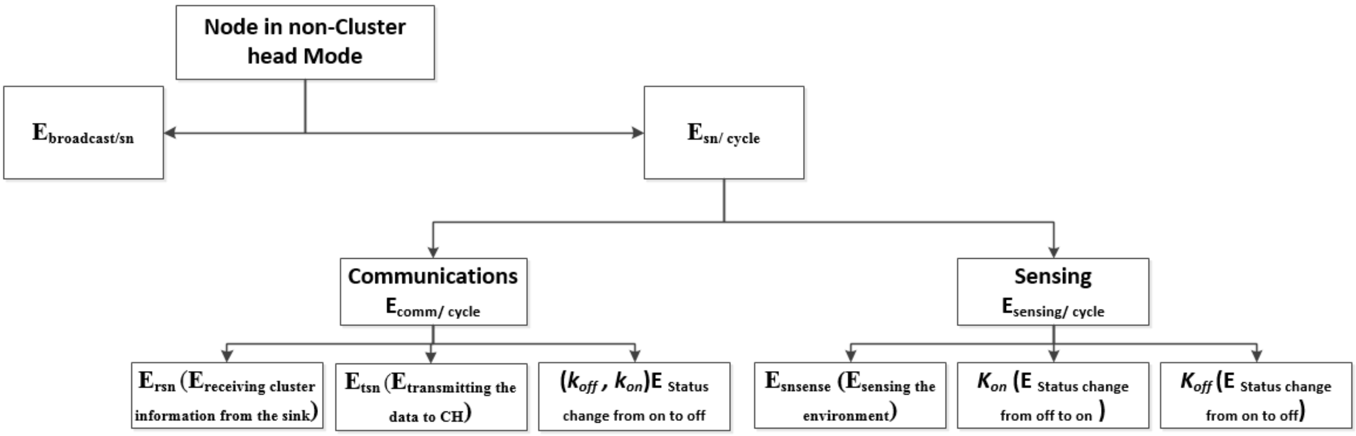
While For cluster member mode

$$E_{total/sn/\,cycle} = E_{sn/\,cycle} + E_{broadcast/sn} \qquad (5\text{-}4)$$

Where $E_{sn/\ cycle}$ is the cluster member mode energy consumption and $E_{broadcast/sn}$ is the broadcasting energy consumption



(a) Cluster Head Mode



(b) Non-Cluster Head Mode

Figure (5-2) Energy Consumption Chart for the Virtualised Clustering Routing (VCR) Protocol

5-3-1 Energy Consumption in Node Discovery (Broadcasting)

As mentioned in chapter four, to start the protocol operation, the sensor nodes should send their information to the sink that will forward it to the NFV server to initiate the clustering function (knows as node discovery).

During this step, the nodes will be assumed to send their information to the sink with transmission power that is equal to the transmission power of the farthest node in the network (node with the greatest distance from the sink).

In this case, Equations (5-5) and (5-6) will be used during this process whether the system is free space or multi-path.

$$E_{broadcast/sn} = E_{elec} * k + \varepsilon_{fs} * k * d^2_{max} \quad \text{when } d_{max} < d_o \qquad (5\text{-}5)$$

Else

$$E_{broadcast/sn} = E_{elec} * k + \varepsilon_{fs} * k * d^4_{max} \quad \text{when } d_{max} > d_o \qquad (5\text{-}6)$$

Where d_{max} is the distance from the farthest node to the sink

$d_o = \sqrt{\frac{\varepsilon fs}{\varepsilon_{amp}}}$ that is approximately = 87.7 m.

Moreover, in order to estimate the energy consumption of the whole network, Equation (5-7) represents the formula that uses

$$E_{broadcasr/netwoerk} = sn * E_{broadcast/sn} \qquad (5\text{-}7)$$

where sn is the number of nodes in the network.

The energy consumption in this step will be taken into account during the initiated cycle only as the nodes send their information in this cycle and do not need to resend it again. The next sections discuss the formulation of the mathematical models, as nodes will either be a cluster head mode or cluster member mode.

5-3-2 Cluster Head (CH) node energy consumption per cycle:

In this section, a mathematical equation for the cluster head node is derived. Once the cluster head node is selected by the server, it will be on all the time during the protocol operation. The main functions of a cluster head will be receiving the sensed data from its members, processing these data (aggregate the data) and then sending it to the sink according to its time slot.

According to this, the energy consumed by a cluster head node (E_{ch}) is ($E_{commch/cycle}$) during the communication domain and ($E_{processch/\ cycle}$) during the processing domain (aggregate the received data). Therefore, the total energy consumed by the cluster head in each cycle is Equation (5-8).

$$E_{ch/cycle} = E_{commch/cycle} + E_{processch/cycle} \tag{5-8}$$

Where

For communication domain, the cluster head's energy will dissipate while receiving the clustering information from the sink, receiving the sensed data from the cluster members within their time slots, and transmitting the sensed data to the sink at the end of each cycle. Hence, Equation (5-9) represents the energy consumed in transmitting every cycle.

$$E_{commch/\ cycle} = E_{rsink} + \sum_{m=1}^{i} E_{\mathrm{rdatasn}}\,(m) + \mathrm{E}_{\mathrm{tdatasink}} \tag{5-9}$$

where i is the number of nodes within the cluster.

E_{rsink} is the energy consumed during receiving cluster information from the sink.

$E_{rdatasn}$ is the energy consumed during receiving the sensed data from the cluster member

$E_{tdatasink}$ is the energy consumed during transmit the sensed data to the sink

By replacing $E_{commch/\,cycle}$ with (5-9), Equation (5-10) will represent the energy consumption during the clustering stage.

$$E_{ch/\,cycle} = E_{rsink} + \sum_{m=1}^{i} E_{\mathrm{rdatasn}}(m) + \mathrm{E}_{\mathrm{tdatasink}} + \mathrm{E}_{\mathrm{processch/cycle}} \qquad (5\text{-}10)$$

On the other hand, at the end of each cycle, the server will monitor the energy of the cluster head node to determine whether it is below a threshold or not. So the E_{rsink} will be calculated when the new clustering information is received.

In addition to that, the amount of energy consumption for each node ($E_{broadcast/Sn}$) in broadcasting will be added at the beginning of the initial cycle.

5-3-3 Non-Cluster Head energy consumption per cycle:

All non-cluster head nodes after receiving the clustering information, will be turned off and remain off until turned back on depending on the application type and reaching its time slot. Therefore, in this mode, the sensor node’s energy will be consumed in communication and sensing domains, as shown in Equation (5-11).

$$E_{sn/\,cycle} = E_{comm/\,cycle} + E_{sensing/\,cycle} \qquad (5\text{-}11)$$

Where

$E_{comm/\,cycle}$ is the energy consumption in communication

$E_{sensing/\,cycle}$ is the energy consumption in sensing.

For the first field, the node will transmit the sensed data to its cluster head according to its time slot and once at each cycle, it will receive the clustering information from the sink. The energy consumption equations in this domain will be as in Equation (5-12)

$$E_{comm/\,cycle} = E_{tsn} + E_{rsn} + k_{off} + k_{on} \qquad (5\text{-}12)$$

Where E_{tsn} is the energy consumed during data transmission to the cluster head

E_{rsn} is the energy consumed during receiving clustering information from the sink.

The status change energy consumption in communication will include two cases:

- From on to off at the end of receiving process (k_{off})
- From off to on in order to transmit the data (k_{on})

Furthermore, part of the sensor node's energy will be consumed during the sensing activity; hence the complete model for calculating the amount of energy consumption will be as shown in Equation (5-13).

$$E_{sensing/\,cycle} = \sum_{l=1}^{p} E_{snsense} + k_{off} + k_{on} \qquad (5\text{-}13)$$

Where $E_{snsense}$ is the energy consumed during the sensing activity

k_{off} and k_{on} are as described above

P is the number of sense activities.

By combining (5-12) and (5-13), the amount of energy consumption for the cluster member node will be formulated, as shown in Equation (5-14).

$$E_{sn/\,cycle} = \sum_{c=1}^{b} E_{tsn}(c) + E_{rsn} + \sum_{l=1}^{p} E_{snsense}(l) + 2k_{on} + 2k_{off} \qquad (5\text{-}14)$$

As in cluster head mode, the node will receive the clustering information only if new clustering occurs so that E_{rsn} will be performed in this case, and the amount of energy consumption for each node ($E_{broadcast/Sn}$) in the broadcasting step will be added at the beginning of the initial round.

5-3-4 Remaining energy level for CHs and Cluster members' (CM) nodes:

As mentioned previously in chapter four, the server will monitor the nodes' energy consumption at each cycle in order to estimate their energy level. Therefore, The NFV server will calculate and update the amount of remaining energy for cluster members (CM) and cluster head (CH) node per cycle using Equations (5-15) and (5-16) respectively.

If the node is cluster member

$$E_{current/\,cycle} = E_{previous} - E_{total/sn/cycle} \qquad (5\text{-}15)$$

If the node is cluster head

$$E_{current/\,cycle} = E_{previous} - E_{total/ch/\,cycle} \qquad (5\text{-}16)$$

Where $E_{previous}$ is the energy level of the nodes at the previous cycle

5-3-5 Total Cluster Energy Consumption per Cycle:

After estimating the energy consumption for each node, the energy consumption for a single cluster will be the summation of the energy consumption for the cluster members and cluster head nodes, as in Equation (5-17).

$$E_{totalcluster/cycle} = \mathrm{E}_{\mathrm{ch/\ cycle}} + \sum_{i=1}^{clsn} \mathrm{E}_{\mathrm{sn/cycle}} \qquad (5\text{-}17)$$

Where clsn is the number of nodes in the cluster.

5-3-6 Total Network Energy Consumption per Cycle:

In order to estimate the amount of energy consumption for the whole network, the total energy consumption for the network will be the summation of the energy consumption of all clusters within the network, as in Equation (5-18).

$$E_{totalnet/\ cycle} = \sum_{i=1}^{C} (\mathrm{E}_{\mathrm{totalcluster/cycle}})_i \qquad (5\text{-}18)$$

Where C: the total number of clusters within the network and $\mathrm{E}_{\mathrm{totalnet/cycle}}$ is the energy consumption for a cluster per cycle.

5-4 Analysis of power consumption in the LEACH protocol

To understand the clustering function and the number of communications during this function, the behavioral of LEACH protocol in terms of number of communications will be analysed mathematically in order to compare between the VCR and LEACH protocols. According to the details and communications diagram of LEACH protocol mentioned in Chapter

3, Figure (3-8), a sensor node consumes its energy to perform various activities, such as clustering, processing and sensing.

The general Equations for the nodes in either cluster head mode or cluster member mode is illustrated in Equations (5-19) and (5-20) respectively.

If the node's role is clsuter head

$$E_{chtotal} = E_{commch} + E_{processtotal} + E_{agg} \quad (5\text{-}19)$$

Where E_{commch} is the energy consumption in communication field

$E_{processtotal}$ is the energy consumption in processing activities

E_{agg} is the energy consumption in data aggregation

However, if the node is a cluster member

$$E_{sntotal}=E_{commsn}+ E_{sensing} + E_{processtotal} \quad (5\text{-}20)$$

Where E_{commsn} is the energy consumption in communication field

$E_{processtotal}$ is the energy consumption in processing activities

$E_{sensing}$ is the energy consumption in sensing

5-4-1 Energy Consumption in Processing

The first energy consumption domain for the nodes in LEACH will be the consumption that occurs during the processing where the necessary information should be calculated and checked to build the clusters. Hence, the nodes consume energy in order to perform various processing activities as processing to generate the random value (r) between 0 and 1, processing to calculate the threshold value (TH), and processing to check whether the node is a cluster head or not.

Hence, the energy consumption equation for this step is shown in Equation 5-21:

$$E_{processtotal}=E_{processrand}+E_{processth}+E_{procrsscheck} \quad (5\text{-}21)$$

Where

$E_{processrand}$ is energy consumption for random value generation

$E_{processth}$ is energy consumption for threshold calculation

$E_{procrsscheck}$ is energy consumption for checking

Moreover, the node consumes its energy in the communication field to perform transmission with other sensor nodes and receiving from the sink or other sensor nodes. After completing the processing, the next function for the sensor node will be the clustering. In clustering, the sensor node will be responsible for the cluster head selection and cluster formulation.

As in the proposed protocol, the sensor node mode can be in two different modes; either cluster head mode or non-cluster head mode.

5-4-2 Energy Consumption for Cluster Head Mode:

In this case, the sensor node will be treated as cluster head; therefore, its energy will be dissipated in communication and processing and data aggregation.

The energy consumption in communication field contains various transmitting activities. For instance, transmitting the CH announcement to other SNs, transmitting the time slot to the cluster memebrs, transmitting the CH announcement to the sink, transmitting the sensed data to the sink), receiving activities such as receiving the join request from other SNs, receiving the sensed data from the cluster members and receiving its time slot from the sink.

For $E_{processtotal}$ represent the processing energy consumption as illustrated in Equation 5-21. While E_{agg} is the data aggregation energy consumption

The final Equation for this field is as shown in (5-22).

$$E_{commch} = E_{tanc} + \sum_{m=1}^{z} E_{ttime}(m) + E_{tsink} + E_{tdata} + \sum_{j=1}^{w} E_{rjr}(j) + \sum_{a=1}^{d} E_{rdata}(a) + E_{timesink} \tag{5-22}$$

Where z = the number of transmissions for the time slot packet sent from CH (which is based on the total number of sensor nodes within the cluster),

d = the amount of received sensed data (which relies on the total number of cycle within the cluster),

w = the number of join requests received from the sensor nodes to join the cluster.

E_{tanc} = the energy consumption for transmitting the CH announcement to other SNs

E_{ttime} = the energy consumption for transmitting the time slot to the cluster memebrs

E_{tsink} = the energy consumption for transmitting the CH announcement to the sink

E_{tdata} = the energy consumption for transmitting the sensed data to the sink

E_{rjr} = the energy consumption for receiving activities such as receiving the join request from other SNs)

E_{rdata} = the energy consumption for receiving the sensed data from the cluster members

$E_{timesink}$ = the energy consumption for receiving SN time slot from the sink.

By substituting the formulas of Equations (5-21) and (5-22) in Equation (5-19), the new equation for the energy consumption is as shown in Equation (5-23).

$$E_{chtotal} = E_{processrand}+E_{processth}+E_{procrsscheck}+E_{tanc} + \sum_{m=1}^{z} E_{ttime}(m) + E_{tsink} + E_{tdata} + \sum_{j=1}^{w} E_{rjr}(j) + \sum_{a=1}^{d} E_{rdata}(a)+E_{timesink}+E_{agg} \quad (5\text{-}23)$$

5-4-3 Energy Consumption for non-Cluster Head Mode:

Meanwhile, for the other mode, which is a cluster member, energy consumption's includes the communication and sensing activities.

The fields of the transmitting and receiving activities performed by the node are as follows: transmitting the join request, transmitting the sensed data to the cluster head, receiving the CH announcement and receiving its time slot for transmission, as illustrated in Equation (5-24)

$$E_{commsn} = E_{tjr} + \sum_{k=1}^{b} E_{ranc}(k) + \sum_{s=1}^{f} E_{tdataCH}(s) + E_{rtime} + k_{off} + k_{on} \quad (5\text{-}24)$$

Where

E_{tjr} is the energy consumption for transmitting the join request

$E_{tdataCH}$ is the energy consumption for transmitting the sensed data to the cluster head

E_{ranc} is the energy consumption for receiving the CH announcement

E_{rtime} is the energy consumption for receiving its time slot for transmission

b is the number of receiving the CH announcements

f is the number of data transmissions

Furthermore, the energy consumption during the status change will be assumed as a constant value, e.g. the status change from on to off (k_{off}) (turn off after joining a cluster) and a status change from off to on (k_{on}) (turn on when an event occurs, or it is time for transmission).

In the same way, the sensor node will consume its energy in the sensing activity. To calculate this amount, Equation (5-25) will be used:

$$E_{sensing}=\sum_{g=1}^{p} E_{snsense}(g) + k_{off} + k_{on} \quad (5\text{-}25)$$

Where $E_{snsense}$ is the energy consumed during the sensing activity

P = the number of sense activities

The status change energy consumption in communication will include two cases and as described previously, k_{off} and k_{on}.

On the whole, for the sensor node in the network, the energy consumption formula is as shown in Equations (5-26)

$$E_{sntotal}= E_{processrand} + E_{processth} + E_{procrsscheck} + E_{tjr} + \sum_{k=1}^{b} E_{ranc}(k) + \sum_{s=1}^{f} E_{tdataCH}(s) + E_{rtime} + \sum_{g=1}^{p} E_{snsense}(g) + 2k_{off} + 2k_{on} \quad (5\text{-}26)$$

By analysing the mathematical models for the proposed protocol (VCR) and LEACH during the clustering function and in terms of the number of communications (the amount of transmission and receiving), it showed that there is a reduction in the number of communications during the clustering function between the two protocols for the cluster head node and cluster member, as described in Table (5-1).

For the proposed protocol, the cluster head node has three communications (received or transmitted), while in LEACH there are seven, which means that there is a 42.85% reduction in the number of communications and this will affect the total amount of energy consumption for the node.

Furthermore, for the cluster member node, the reduction is approximately 50%, because in the proposed protocol the nodes have two communication activities compared with four in LEACH.

Table (5-1) Number of Communications for VCR and LEACH

Node Mode	**Number of Communications in in VCR**	**Number of Communications in LEACH**
Cluster Head	3	7
Cluster Member	2	4

5-5 Summary

According to previous explanation, the proposed protocol (VCR) based on the centralised operation where the server will be responsible for the network management during the protocol operation as well as estimate the node's energy consumption during the clustering process based on an energy estimation model.

The purpose of the analytical model is to estimate the amount of energy consumption during the network's operations. The mathematical model takes into account the general fields that the nodes consume its energy on such as transmission, receiving and status change.

Moreover, in order to find the percentage of the communication reduction in term of number of communications for the nodes, a mathematical model based on the communication operation of the LEACH protocol had been derived and explained.

Chapter Six

Simulation, Validation and Evaluation

6-1 Introduction

This chapter discusses the simulation of the VCR protocol and the validation and evaluation. The simulation was based on the MatlabR2016a environment, which is a high-level language and interactive environment for numerical computation, visualisation, and programming.

As described in chapter four, after completing the cluster formation and the cluster head selection, the energy consumption/cycle was calculated. This procedure was repeated for different topologies and parameters to find the average values of the energy consumption to be used for the validation and evaluation steps.

6-2 Experimental Design

6-2-1 Validation Experiments:

The aim of the validation process is to determine the efficiency of the proposed protocol in minimising the amount of energy consumption of the sensor nodes under various conditions and, thus, improving network lifetime. To validate the behaviour of the proposed protocol, it will be tested under different experiments, as listed:

1- Experiment One: The simulation is repeated for a varied number of clusters, with the number of nodes of 100 to find the optimum number of clusters in terms of minimum energy consumption per cycle.

2- Experiment Two: After the optimum number of clusters have been found and fixed, and the operation will be tested depending on:

  - Sensing area (for various area sizes (100*100) and (500*500)).
  - Sink Position (Placing the sink position inside or outside the sensing environment).

3- Experiment Three: the optimum number of clusters for different number of nodes (n=50,150,200) will be found and verified by comparing it with the data from the mathematical analysis.

4- Experiment Four: The amount of energy consumption will be measured based on various node density (by fixing the area size and changing the number of nodes deployed in the sensing area) (N=50,100,150,200).

5- Experiment Five: network lifetime was measured based on First Node Dead (FND) under dynamic and static clustering for the proposed protocol.

6-2-2 Evaluation Experiments:

1- In the evaluation, the proposed protocol was tested to find whether the research objective, which is improving the network lifetime, had been achieved or not. This was done by:

  - Experiment Six: Comparing the results obtained from the proposed protocol, which is the First Node Dead (FND) measurement simulation with the existing clustering based protocols results, which are LEACH (for distributed type) and LEACH-C (for centralised type).

2- Furthermore, an additional experiment (Experiment Seven) was simulated in order to investigate the costs of the start-up stage in, LEACH and LEACH-C.

3- Finally, in terms of static clustering, Experiment Eight investigates the difference in terms of FND between static VCR and static LEACH.

6-3 Network Topology Setup:

The aim of the simulation is to test the protocol operation and measure the amount of energy consumption per cycle for the network during the protocol operation with various topologies and parameters such as a different number of nodes, sink position and sensing area. The basic parameters used are as shown in the Table (6-1).

The implementation began with the sensor nodes that distributed randomly in two dimensions sensing area in the simulation environment of M * M area size. As mentioned previously, the nodes will be in fixed position as soon as it is deployed. The pseudo codes for sensor node and sink deployment are as shown in code (6-1).

As mentioned previously, the sink will be initialised with the size of the network (number of nodes in the network).

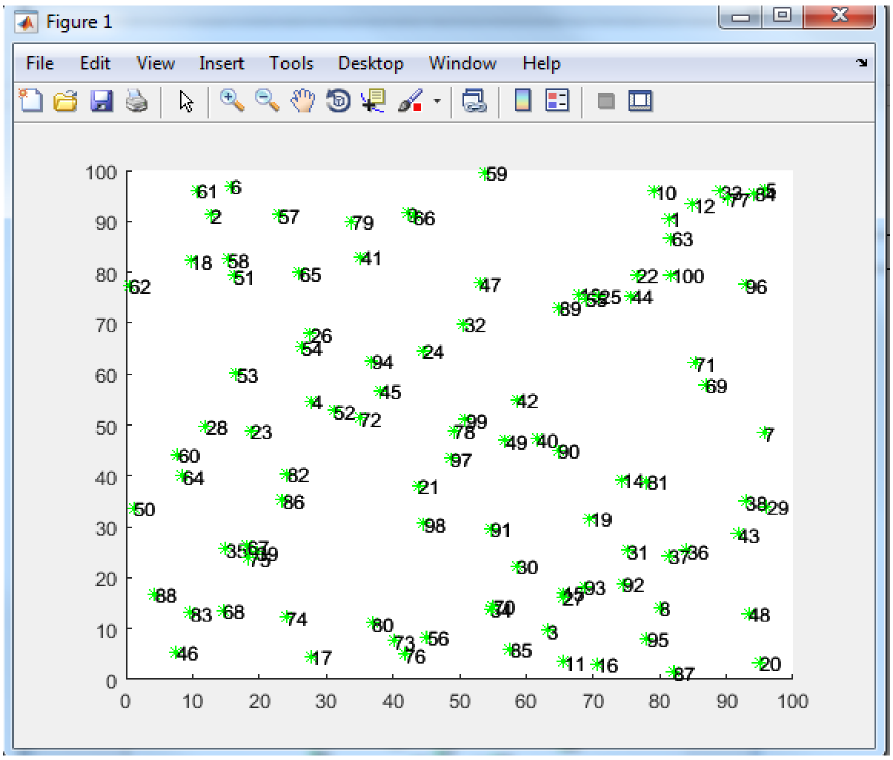
Figure (6-1) is an example of the implemented network topologies, and the full topologies and their seeds are in Appendix D.

```
%Define network area (MxM)=Xm,Ym

For i =1 to total number of node (N)

Xsn coordination of node(i) = rand(Xm);Ysn coordination of node (i)=rand(Ym)

Node type='N'=ordinary sensor node

%For sink position

Xsink coordination for sink=Xm/2 ; Ysink coordination for sink=Ym+75 (for
outside)

Xsink coordination for sink=Xm/2 ; Ysink coordination for sink=Ym/2 (for inside)
```

Code (6-1) Pseudo Codes for Sensor Node and Sink Deployment

Table (6-1) Simulation Parameters

Parameters	Values
ε_{fs} =energy consumption in power amplifier in free space mode (short distance), its used if $d^n<d_0$ (if n=2)	10 pJ/bit/m^2
E_{elec}	50 nJ/bit
Packet Size	4000 bit
ε_{amp}= energy consumption in power amplifier in two ground model (long distance), its used if $d^n>d_0$ (if n=4)	0.0013 pJ/bit/m^4
do is the threshold distance between the sender and the receiver and its depend if the channel propagation is free space model or two ray ground model	87.7 m
Bit rate	1 Mbps
Initial Energy	2 J
Energy to aggregate 1 bit	5 nJ/bit/signal



Figures (6-1) Network Topology Example

6-4 Calculation of the Optimum Number of Clusters

As explained in chapter four, if the number of clusters within the network is less or more than the optimum value, will led to increase the energy consumption and this will affect the network lifetime. Therefore, the aim of calculating the optimum number of clusters in the network is to minimise the protocol complexity and energy consumption and improve the network lifetime. After completing the calculation process, the server starts to find the expected number of clusters (C), and this is done using Equation (4-5), as mentioned in chapter four.

For the various parameters used during the simulation process, the expected number of clusters for each case is as shown in Table (6-2). The simulation aims to run the protocol for each value of C in order to verify these values.

Table (6-2) Range of Clusters

Area 100 * 100 , Sink coordination (50,175)	
Number of Nodes	Expected range of optimum number of clusters
50	1< C < 4
100	1< C < 6
150	1 < C < 7
200	1 < C < 8

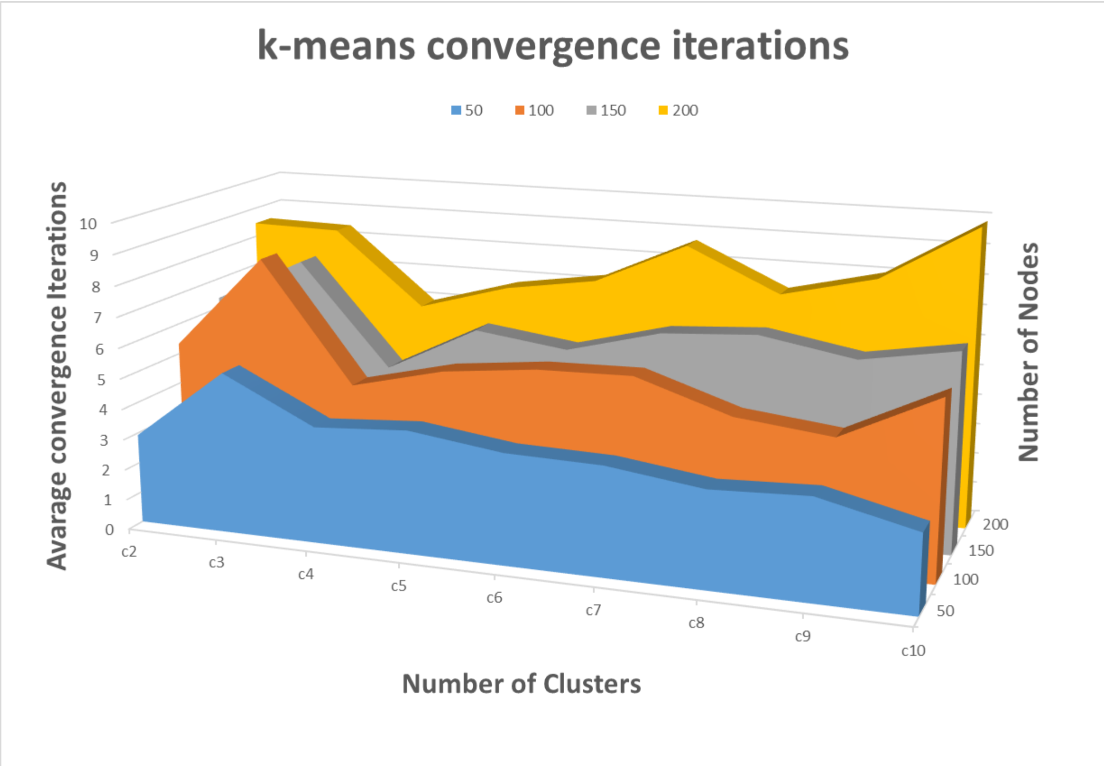
The simulation results of the following parameters will be used to compare with LEACH and LEACH-C:

1- Number of Nodes (n=100).
2- Network area size (100*100).
3- Sink position outside the sensing area (50,175)

6-5 Cluster Formation

Based on the expected range of an optimum number of clusters (C) in the network found from the previous step, the clusters will be formed using the concept of k-means algorithm, as explained in chapter four. The process is repeated with various iterations until convergence occurs (the cluster shape and members do not change).

As mentioned previously, the convergence condition of the k-means cannot be random or fixed because it is changeable with various number of clusters and node density in the network. This experiment is conducted to verify this fact. Therefore, for the convergence iterations of the k-means of the proposed protocol, the simulation is repeated under various topologies and parameters in order to find the iterations convergence for each number of clusters and number of nodes. Figure (6-2) represents the average convergence iterations from different network topologies, node density within the clusters and different number of clusters within the network. The detailed figures for different topologies are in Appendix E.



Figures (6-2) K-means Average Convergence Iterations

From these Figure, it is concluded that the number of iterations is not fixed and it changes based on various parameters such as nodes position, the number of clusters within the network as well as the nodes density within the clusters.

6-6 Results and Validation

As mentioned previously, the validation of the proposed protocol includes various experiments in order to test the network's behavior based on the average energy consumption per cycle. These test experiments will be described in the next sections.

6-6-1 Energy Consumption Calculation

After the clustering function (cluster formation and cluster head selection) are completed, the clustering information will be sent to the nodes via the sink in order to start the operation.

As mentioned previously, the server's responsibility is to monitor the network behaviour, cluster heads and member nodes' energy level in order to update the information and clustering process. This will be done based on the proposed mathematical model to calculate the amount of energy consumption for the sensor nodes.

The energy consumption per cycle has been calculated using the proposed mathematical model, the calculation procedure was repeated for different network topologies, and the average values of the energy consumption were found and used during the evaluation step. As regards the optimum number of clusters in the network, the optimum number of clusters will be found and verified.

As mentioned previously, the protocol will be tested with different experiments, as follows:

1- Experiment One: number of nodes 100, sink location 50,175 and sensing area size (100*100):

In this experiment, the network consists of 100 nodes deployed randomly in the 100*100 sensing area. The test is based on 15 different topologies with a number of clusters between (1 to 10). The aim of this scenario is to find the optimum number of clusters based on minimum energy consumption per cycle, and verify the values in a Table (6-2). The result is shown in Figure (6-3).

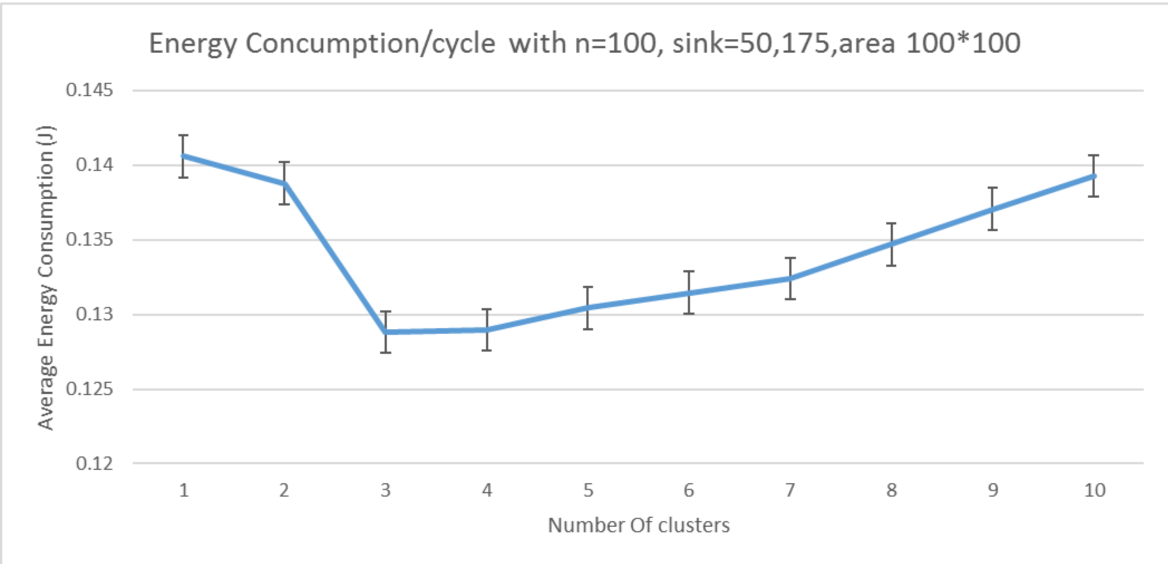


Figure (6-3) Average Energy Consumption with N=100

The line graph shows the amount of energy consumption per cycle with a different number of clusters in the network. From this graph, the amount of energy consumption is varied from different number of clusters within the network. For each cluster, the behaviour of the network is changeable with the number of nodes in the clusters, the distance among the nodes with their cluster heads as well as the distance between the cluster head nodes and the sink.

Furthermore, the value of an optimum number of clusters from the Table (6-2) was verified based on the result, and the optimum number of clusters in terms of minimum energy consumption is 3. During the rest of the simulation process, the number of clusters will be set to 3.

In WSN, many parameters should be taken into account in the design of any protocol. Each of these parameters affects the behaviour of the system in terms of energy consumption; the common parameters are the number of nodes in the network, the sink position and the size of the sensing area. Therefore, by fixing the number of the cluster to 3, the network was tested under various conditions, such as:

- Changing sink position (inside and outside sensing area)
- Changing the size of the sensing area (100*100, 500*500).

The full details of these experiments are explained in the next sections.

2- Experiment Two (change Sink Position and area size):

This experiment is based on the position of the sink, which had an important impact on the energy consumption of the network because of the communication among the cluster heads and the sink. Therefore, the simulation was run with the following values, and the energy consumption values of the network are as shown in Figure (6-4).

- Different sink position (inside and outside the network area), its coordination is (50, 50) and (50,175).
- Number of nodes change (50,100,150,200).
- The sensing area is (100*100) and (500*500).

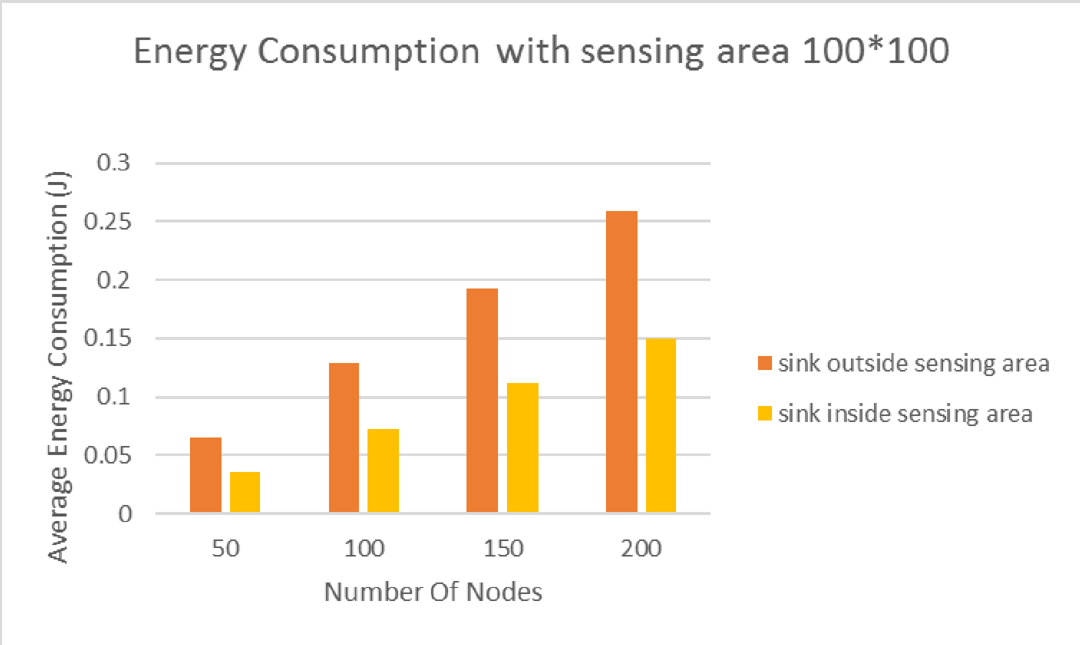


Figure (6-4) Average Energy Consumption with Varying Sink Position

The Figure (6-5) represents the amount of energy consumption per cycle based on sink position. As can be seen from the figure, the network consumed lower amounts of energy when the sink was located inside the sensing area because the distance among the CHs and the sink decreased and thus influenced the amount of energy consumption. The same experiment was repeated with larger sensing area (500*500).

As illustrated in this Figure, the network had significant levels of consumption when the sensing area size is increased because the distance among the nodes in the clusters and the distance between the CHs and the sink increased and thus will affect the energy consumption of the nodes. In addition, the amount of energy consumption of the network is more reliable when the sink is located in the network area.

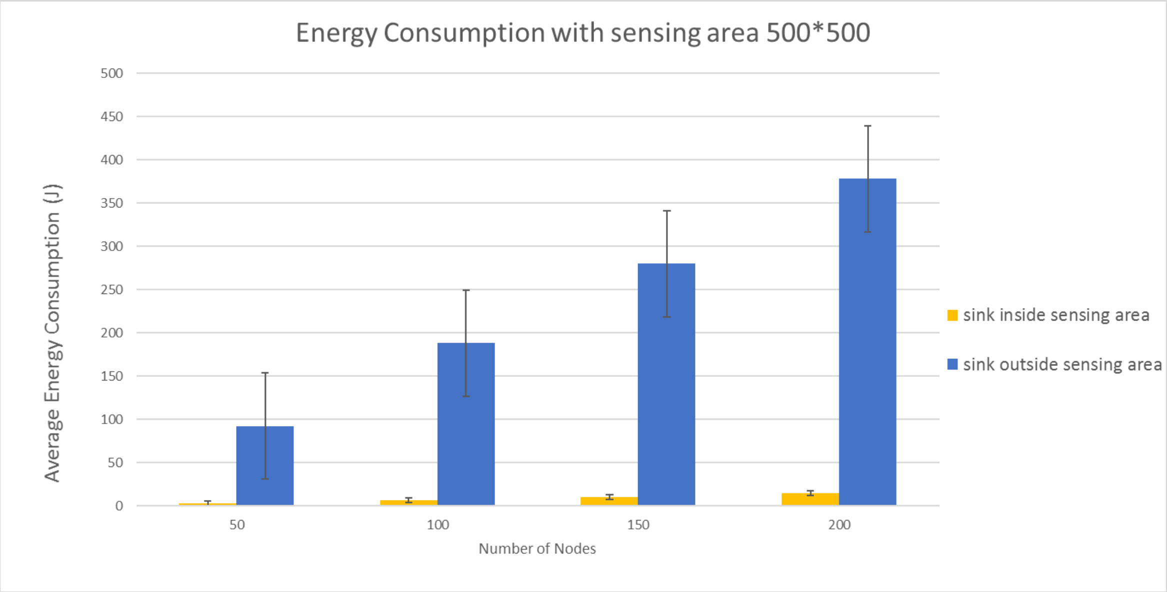


Figure (6-5) Average Energy Consumption with different sensing area size

3- Experiment Three (based on different number of clusters)

As described in chapter four, the optimum number of clusters depends on different parameters such as a number of nodes, and sink position as well as the size of the sensing area. Therefore, the network was tested under a different number of clusters in the network in order to find the optimum cluster under a different number of nodes and verify the values from the Table (6-2), as described below:

- **Scenario One : When Number of Nodes = 50:**

In this test, the simulation was run on a range of clusters between (1 to 5) in order to find the optimum number of clusters when the number of nodes in the network is 50, as shown in Figure (6-6). The optimum number of clusters from this figure C=2 and the value from the Table (6-2) were verified.

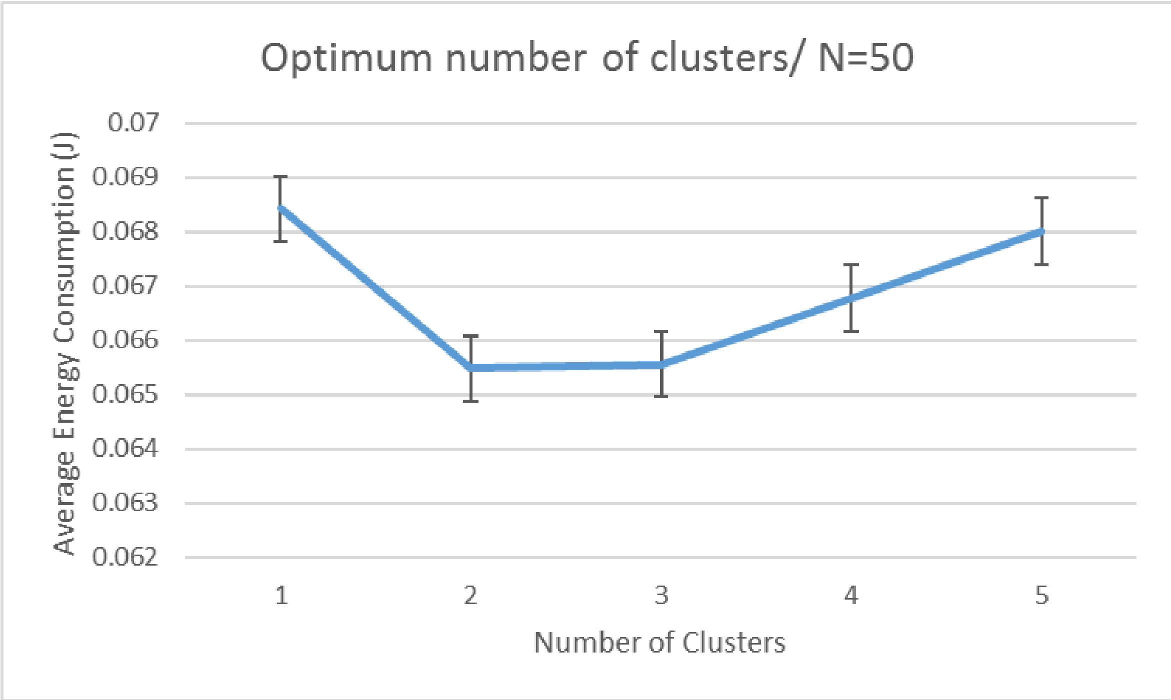


Figure (6-6) Optimum Number of Clusters for N=50

- **Scenario Two: When Number of Nodes = 150:**

Likewise, and as in the previous scenario, the protocol was tested with 150 nodes where the range of clusters was between (1 to 8) to find the best number of clusters in terms of minimum energy consumption and compare it with Table (6-2) for verification. Figure (6-7) illustrates the results of this step. From the results, the optimum number of clusters, in this case, is 4.

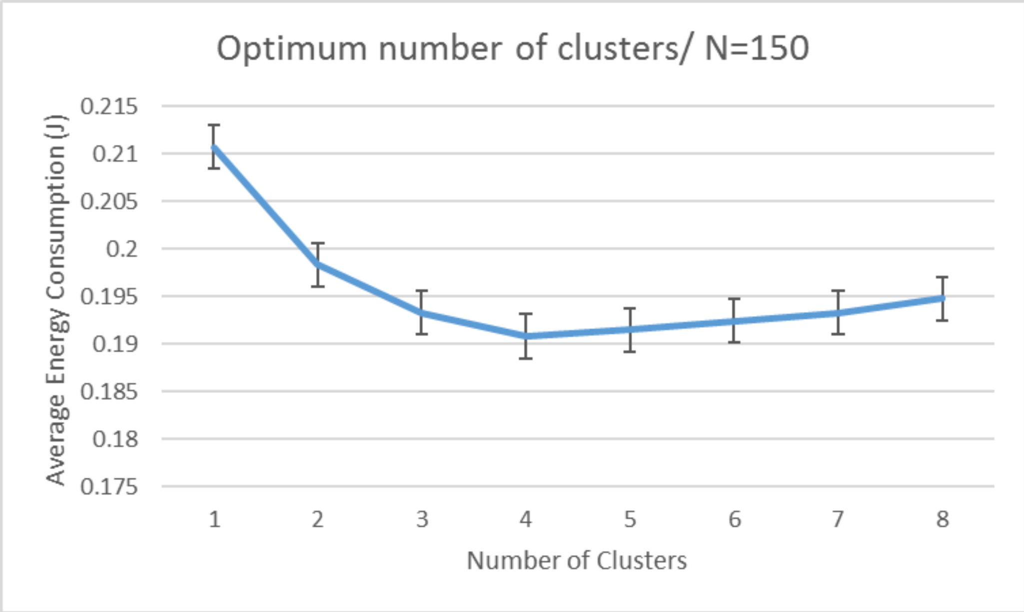


Figure (6-7) Optimum Number of Clusters for N=150

- **Scenario Three: When Number of Nodes = 200:**

Similarly to the previous scenario, the simulation was re-run with 200 nodes deployed randomly in the network and a range of clusters (1 to 9). The results are presented in Figure (6-8). From the results, it can be seen that the optimum number of clusters is 5 and this is within the range from the Table (6-2).

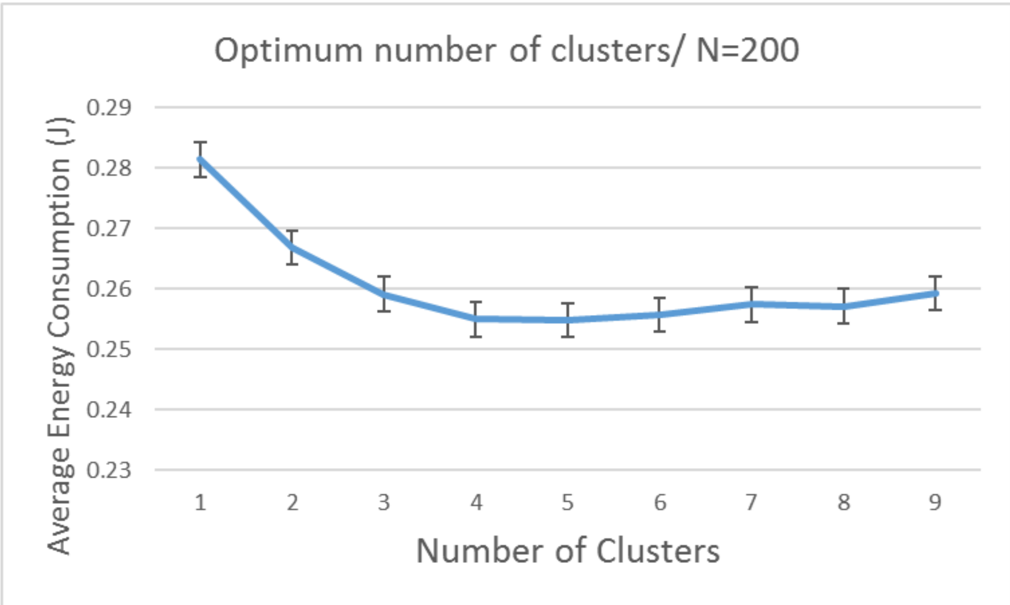


Figure (6-8) Optimum Number of Clusters for N=200

4- Experiment Four: Various node density within the clusters (Different number of Nodes):

In this experiment, the protocol was tested based on the following parameters:

- Various number of nodes (50,100,150,200).
- The sensing area is (100*100).
- Sinks position is outside the network area (50,175).
- Various range of clusters within the network (1 to 5).

The energy consumption of the network is as shown in Figure (6-9). The figure shows the energy consumption of the network with a different number of nodes in terms of number of clusters within the network, these nodes are distributed randomly in the 100*100 sensing area with sink position outside the sensing area.

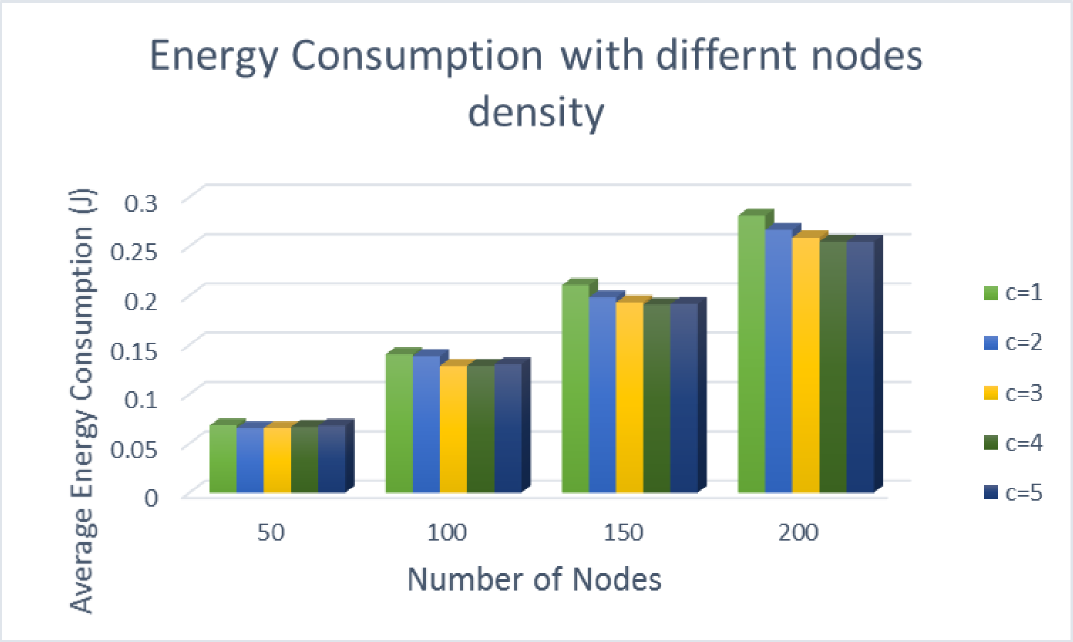


Figure (6-9) Average Energy Consumption with different nodes density

According to the data in this graph, in terms of nodes density within the network, the amount of energy consumption is increased when the number of nodes increases, this is because the number of nodes that the cluster head needs to communicate with is high. Furthermore, the energy consumption within the clusters is changeable with the various number of nodes inside each cluster and number of clusters in the network. To summarise the results from this scenario, the nodes density had a significant impact on the energy consumption of the clusters and the whole network.

5- Experiment Five: Dynamic and Static clustering in VCR

The time for the node to act as a cluster head had a significant impact on the amount of energy consumption and thus, in turn, affected the network lifetime. Therefore, rotating the cluster head roles among the nodes within the cluster is important for achieving energy balance. Based on the protocol assumptions, the cluster head rotation depends on a specific energy level of the cluster head node. The proposed protocol was re-tested based on another criterion that is based on static clustering, which means that as soon as the node became a cluster head, it did not change. In spite of the static clustering reducing the overhead of the cluster formation and cluster head selection, it will add an extra load of the cluster head node and cause it to drain its energy fast, which is inefficient and minimises the network lifetime.

Figure (6-10) represents the benefit of dynamic clustering by compared the network lifetime (FND) in dynamic and static clustering of the VCR. From this figure, it is obvious that the network lifetime is maximised when the rotation process is dynamic because in static clustering as soon as the cluster head drains its energy, this will isolate the whole nodes within the clusters and end their lifetime.

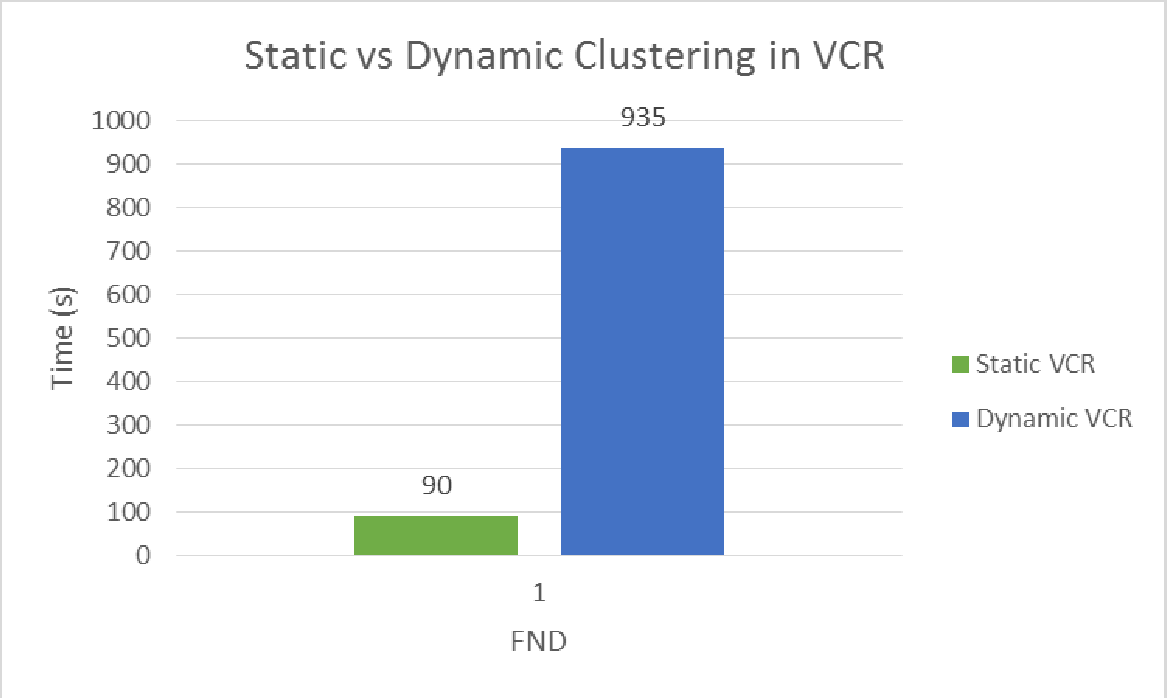


Figure (6-10) Static Vs Dynamic Clustering in VCR

6-7 Evaluation

As mentioned previously, in the evaluation step, compression between the results obtained from the proposed protocol and the available results of traditional clustering routing protocols will be reviewed, and the selected routing protocols in this process will be LEACH protocol as an example for distributed clustering protocol and LEACH-C as an example for centralised clustering protocol. The results of the simulation with n=100, area 100*100 and sink 50,175 will be used during the comparison process.

6-7-1 Experiment Six: Lifetime measurement based on First Node Dead (FND)

As described in chapter two, the network lifetime in WSN can be defined as the time duration between the start of the communication process and first, half or last dead sensor nodes. In this thesis, the First Node Dead (FND) will be used to represent the network lifetime.

The important difference between the proposed protocol, LEACH and LEACH-C is the round timeline, and the round time depends on a pre-define time value, which has been defined by the researchers. Also, the number of cycle is not fixed and depends on a specific time as well.

For LEACH-C, the sending process for the nodes information at the beginning of each round adds an extra overhead for the nodes. However, in this thesis, and as mentioned previously, the cluster head selection process depends on a certain energy threshold, and the number of a cycle of the round depends on the number of clusters in the network, and the checking process occurs at the end of each cycle.

The cluster management during the protocol operation is separated, which means the behaviour of the clusters is not fixed and depends on the number of nodes within the clusters. This scheme will manage the time for nodes to become cluster heads and thus, will affect the lifetime of the node.

Furthermore, by moving the setup stage into the smart environment (NFV server in cloud system), this will lead to minimising the amount of communication required for this stage and prevent the nodes from sending their information each time at the beginning of each round. All these factors affect the network lifetime, as shown in Figure (6-11) that illustrates the comparison between the VCR, LEACH and LEACH-C in terms of FND.

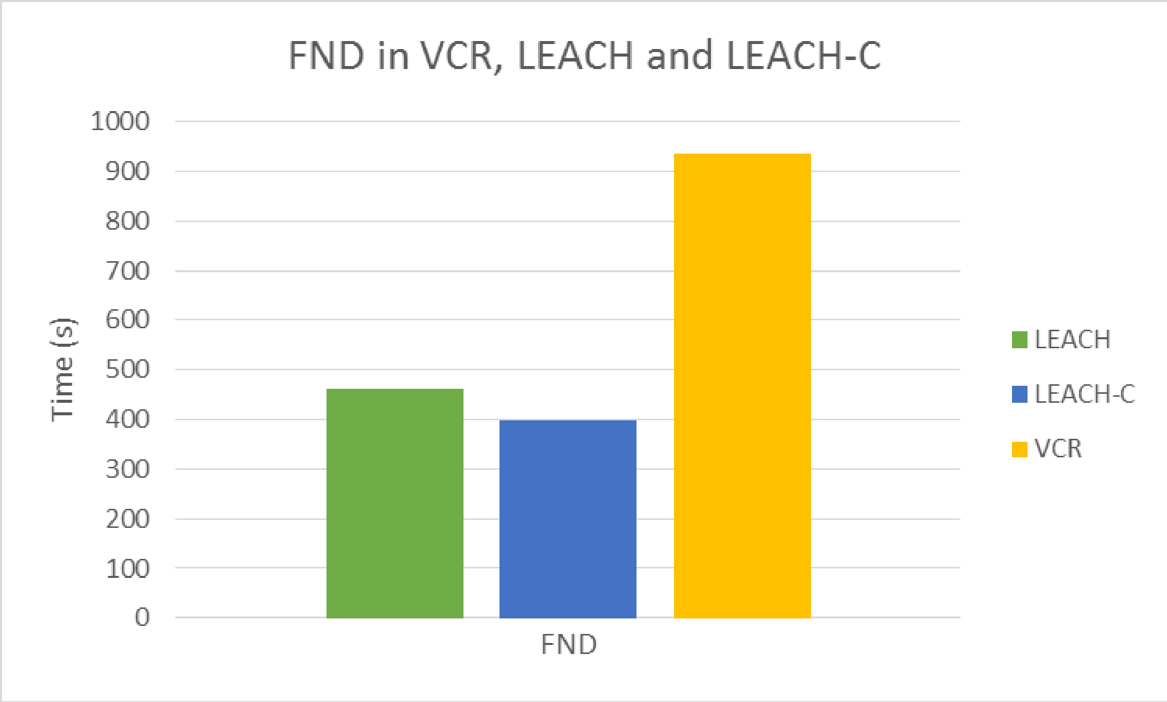


Figure (6-11) Comparison among Proposed Protocol, LEACH and LEACH-C

From this bar chart, the proposed protocol has outperformed LEACH and LEACH-C by doubling the network lifetime; this is considered a significant improvement in the network because of the new protocol minimising the overhead of the cluster formation and cluster head selection.

6-7-2 Experiment Seven: Start-up Cost

In LEACH, the cost of the startup stage contains various messages exchanged in order to start building the clusters such as cluster head's advertisement, the joining request message from the normal node and the time slot for each cluster member. On the other hand, for LEACH-C, the startup step has more energy consumption than the LEACH because of the transmission process for nodes information to the sink that occurs at the beginning of each round.

At the beginning of the proposed protocol process, and as mentioned previously, the senor nodes will send a short message to communicate its location and energy level to the base station that in turn will forward it to the NFV server. This message will be sent once and does not need to be sent again because of the utilities of the smart environment provided by the cloud application (NFV server). According to this, the total energy consumption in this stage for the proposed protocol, LEACH and LEACH-C, is shown in Figure (6-12).

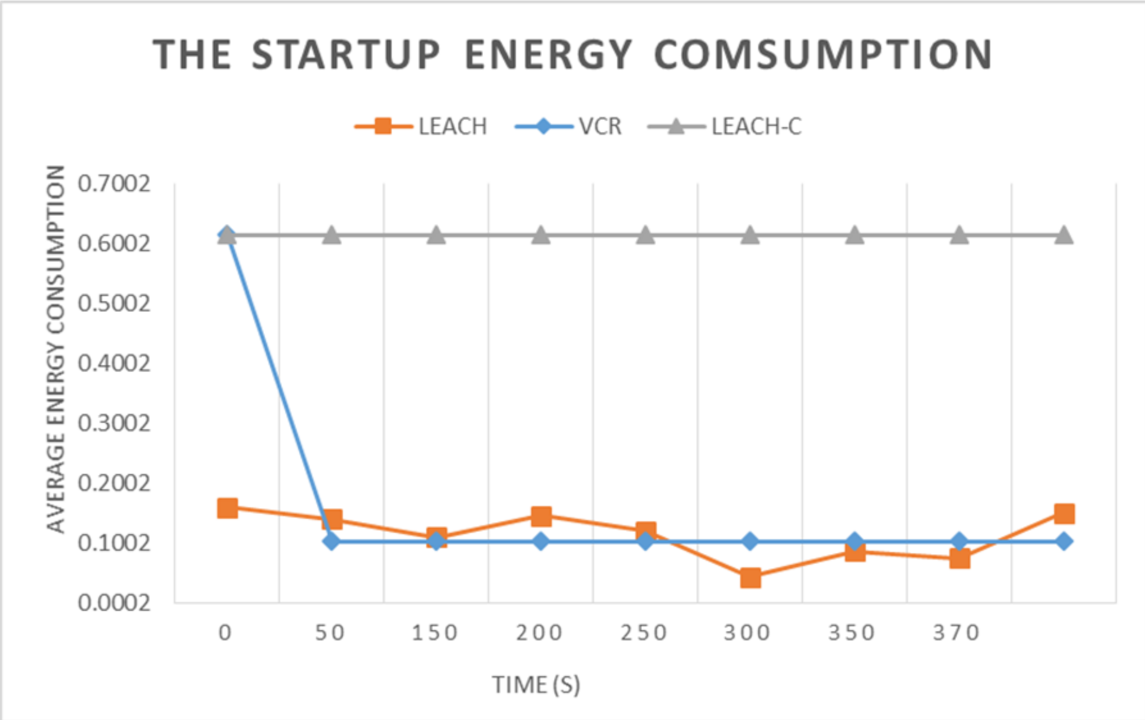


Figure (6-12) Startup Energy Consumption

From this figure, the startup cost in the proposed protocol is high at the beginning of the stage when the nodes transmit their information to the sink, but after that, the consumption is minimised and stable because the node consumes its energy in the same procedure, which receives the clustering information from the server via the sink.

On the other hand, in LEACH, the amount of energy in the startup stage is different in each round because the number of nodes that will be a cluster head is different and thus will affect the amount of energy consumption.

By comparing between the proposed protocol and LEACH, it is obvious that the new protocol consumes more energy than LEACH just at the beginning of the first round and it will be superior to the rest of the protocol operation because of the minimising of the number of communications.

For LEACH-C, the start-up energy consumption is fixed because of the same procedure happening at each round (same transmission process, as the node, sends its information to the sink at the beginning of every new round).

6-7-3 Experiment Eight: CH role Rotation

As mentioned previously, the rotation time for the node to be a cluster head is important to balance nodes' energy consumption. In other words, if the rotation time is fixed, too small or too long, the energy consumption distribution will be unbalanced among the node. Also, checking the node energy at each cycle is important to monitor the network and manage the nodes.

Some clustering based protocols use static clustering, which means as soon as the cluster forms and the cluster head selected, the clusters will be fixed. In spite of this process removes the overhead of the setup stage, but also makes the clusters depend on just one node as a cluster head, and this node will consume all its energy at a fast pace to make the whole cluster isolated from the network and dead.

Figure (6-13) represents the behaviour of the proposed protocol and LEACH protocol for static clustering. It shows that in spite of the static clustering being inefficient for the network lifetime, the behaviour of the proposed protocol is better than the LEACH and duplicates the network lifetime. By using the cloud based technique and static clustering (re-clustering only under certain conditions), the overhead of the set up stage (cluster formation) is reduced.

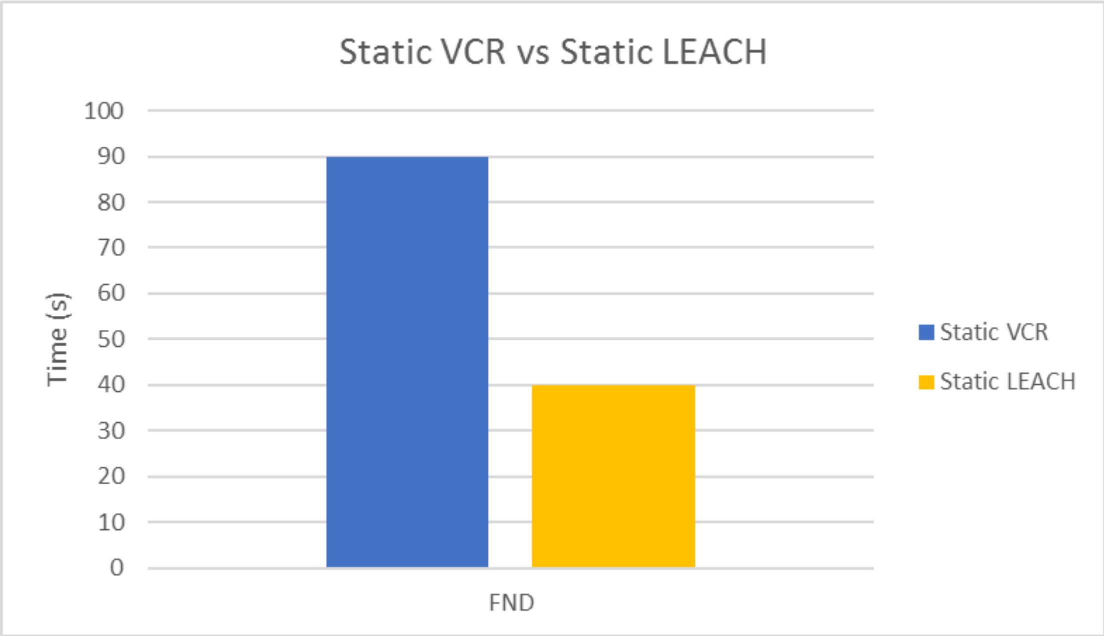


Figure (6-13) Static VCR vs. Static LEACH

6-8 Results Analysis

The analysis of the results has shown how the proposed protocol (VCR) had improved the network lifetime over LEACH and LEACH-C. The virtualised and centralised clustering has improved the cluster formation process and reduce the number of communication during this function in order to minimise the amount of energy consumption during the clustering function. Furthermore, the enhancement in cluster formation and cluster head selection stage led to improve the protocol operation and prolong network lifetime. To summaries the main different point between VCR, LEACH and LEACH-C, Table (6-3) illustrates these differences. To understand the others clustering routing protocols; please refer to table (3-1) in Chapter three.

6-9 Summary

In this chapter, proposed protocol has been implemented, validated and evaluated. The behaviour of the network was tested based on various scenarios and parameters such as a various number of nodes, different sink position as well as different area size in order to validate the operation of protocol. In addition, the optimum number of clusters was found with various numbers of nodes and verified the results from the optimum number of clusters equation.

For the evaluation, the results showed that the VCR is better than the LEACH and LEACH-C protocols in terms of first node dead (FND) and the network lifetime was improved and doubled.

Table (6-3) Comparison among LEACH, LEACH-C and VCR

Protocol	Classification	Basic definition	Advantage	Disadvantage
LEACH	Distributed	- The first protocol in distributed clustering based approach. - The cluster head role is distributed among the nodes. - The clustering approach is based on a random process. - Cluster heads are selected first, then, the cluster will be formed (nodes join the nearest cluster head).	- Better than flat protocols in improving the network's performance. - The number of clusters are changeable for each round	- The random clustering results in an even distribution of CH role among the nodes. - The clusters may not cover the whole network. - Not suitable in mobile networks - There is no guarantee to produce an optimum number of clusters because of the random process. - The round rotation is based on time (does not take into account the energy level of the nodes).
LEACH-C	Centralised (Sink is responsible for the clustering function	- The first protocol in Centralised clustering based approach. - Centralised version of LEACH to improve the network performance and lifetime. - A list of cluster head will be generated based on nodes energy level and will be fixed during the protocol operation. - Cluster heads selected first, then, the cluster will be	- Centralised responsibility by the sink improves network management and control - LEACH-C improves the packets delivery of LEACH by 40%	- Generate a list of CHs nodes, which is unchangeable. - Not suitable in mobile networks. - The round rotation is based on time (do not take into account energy level of the nodes).

		formed (nodes join the nearest cluster head).		
VCR	**Virtualised and Centralised (the server is responsible for the clustering function)**	**- Clusters formed first, after that the cluster heads will be selected - Clusters formed first based on a clustering algorithm (k-means), after that the cluster heads would be selected. - Cluster head selection is based on a cost function that combines the nodes' distance to the sink and their energy level (this cost function is updated at the end of each cycle) - The round rotation is based on a certain condition (using the nodes' current energy level)**	**- The optimum number of clusters is found by the central server to improve network management. - Use nodes energy level, distance to sink and distance among nodes for effeicint clustering fucntion. - By comparing it with LEACH and LEACH-C , the network lifetime had been enhanced to double.**	**- Not suitable in mobile networks**

Chapter Seven

Conclusions and Future works

7-1 Introduction

In this thesis, a new virtualised and centralised routing protocol has been proposed to enhance the network lifetime and minimise the amount of energy consumption that is required to the clustering function in clustering sensor networks. The new protocol utilises the approach of the cloud computing and enables a NFV server to manage and control the network. This chapter introduces the conclusions as well as the future works required of this research.

7-2 Conclusions

Improving the network lifetime and minimise the energy consumption for the sensor nodes were the aim of this thesis. The new protocol represents a design that combines the concept of the network function virtualisation as an application of cloud computing and the smart environment by moving and virtualising a clustering function to be operated on a central server. Using the server concept makes the function sharable and able to be utilised by any WSN. The results show that the new protocol outperforms the existing cluster protocols and network lifetime has been doubled.

In conclusions, and based on the results, using a central server to manage and control the network is efficient to minimised the number and the amount of communications as well as use efficient clustering function will led to balance the energy consumption among the nodes and improve network lifetime.

The objective of this thesis were achieved and will now be summarised in the following paragraphs. Chapter one contained a brief introduction to the system design as well as the main research problem, which refers to the energy consumption in WSN generally and in clustering function precisely. The aim, objectives, hypothesis and contribution of the research were explained and reviewed, and finally, the general steps of the methodology used during this research were included. Furthermore, a simple definition of NFV was also presented in this chapter because of the NFV is the important part of this research.

Moreover, in order to understand the concept of WSN, a full information and background for what WSN means, main components, applications types and the energy consumptions fields and how it can be minimised were outlined in Chapter Two. The characteristics and classifications of the routing protocols were also reviewed, and these reviews helped to identify the various problems in the design of this type of network and find out the main points that should be taken into account during the design of any routing protocols.

To clarify the general concepts clustering functions and the energy consumption problem in the clustering function, a comprehensive literature review was provided in Chapter Three; besides this, the main clustering routing protocols classification of distributed and centralised routing protocols and their types were discussed. As a case study, the details and behaviours of the first clustering protocol (LEACH) were explained.

Various methods can be used to extend network lifetime and reduce the power consumption of the sensor nodes. One of these methods is the reduction in the number of transmitted and received control messages and minimising the computation needed for each node during the stages of cluster formation and cluster head selection. In this thesis, a new clustering based routing protocol known Virtualised Clustering Routing (VCR) Protocol has been introduced. The VCR reduced the number of communications between nodes and minimised the computation overhead in each node. Full details and characteristics of this new protocol were described in Chapter Four. The new protocol uses NFV principles to virtualise the clustering function and move it to a centralised server with considerably higher processing capabilities. This technique produce more energy efficient clustering and allows the server to apply machine-learning techniques (k-means) to the clustering function, which is based on the square distance among the nodes; this achieves the clustering in the best shape with minimum distance among nodes.

Furthermore, as mentioned in the description of k-means algorithm, the final clusters formed after certain convergence iterations, that cannot be random or constant. Therefore, in order to find these convergence iterations, k-means have been simulated for various testes, which based on different number of nodes in the network and various network topologies.

Furthermore, by combining the distance to sink and current energy level, this achieves the best selection for the cluster head. Also, the duration of the node to be a cluster head is necessary to guarantee the energy consumption distributed among the nodes and prolong network lifetime.

Then, as mentioned previously, the energy level of the node will be monitored and estimated by the server, this will be done by the proposed analytical model that was introduced in Chapter Five. This model takes into consideration the various fields in which the nodes consumed their energy and modified it according to the proposed protocol operation. Furthermore, to illustrate the number of communications in the LEACH protocol, a mathematical model for LEACH was derived and explained in this chapter. The purpose of this model to make a compression with the proposed protocol in terms of numbers of communications during the clustering function.

The simulation and tested scenarios for the protocol were introduced in Chapter Six. The protocol was tested based on various scenarios such as changing a number of nodes in the network, changing the sink position as well as modifying the size of the coverage area. Moreover, the most important issue is a centralised protocol to find the optimum number of clusters to enhance the protocol performance. Therefore, this value was determined based on different scenarios as described in this Chapter.

The validation showed that the behaviour of the protocol is variable and depends on various parameters such as nodes density, sink position as well as the sensing area size. The results showed that the amount of energy consumption is increased when the sink is located outside the sensing area and the sensing area size is maximised because the energy consumption depends on the distance between the nodes within the clusters and between the cluster heads and the sink.

For the evaluation, LEACH and LEACH-C were used to evaluate the design in dynamic and static environment. The selection of these protocols were done because they represent the first and popular protocols in distributed and centralised clustering and they were the base for most of the available clustering protocols.

The evaluation was based on a comparison among the VCR protocol, the LEACH and the LEACH-C with different criteria such as First Node Dead (FND) and start-up cost. It can be concluded that a significant reduction in the communication cost was achieved and thus, affects the network lifetime. The results regarding First Node Dead (FND) showed that the new protocol outperforms the LEACH and LEACH-C and the network lifetime was doubled.

7-4 Future Works

The following ideas could be used as a future development of this research:

1- Implement the design in real environment in order to study the protocol operations in this field.
2- As the style of intra and inter communications were based on single-hop, the sensor nodes consumed a significant amount of energy during the protocol operation when the size of the network was increased. Therefore, the protocol should be tested by changing the communication style to be in the multi-hop scheme for either intra or inter communication or both and find how the system will perform in larger network sizes.
3- In some WSN applications, the mobility of nodes is necessary to perform tracking or monitoring tasks. Therefore, the mobility of the sensor nodes during the protocol operation can be adopted in future work.
4- The implementation is based on a single sink as a data gathering point. In a future work, multi-sinks could be included to distribute and balance the energy consumption and investigate the network behaviour. In addition, make the sink responsible on the starting of the operation.

Publications

The following is the list of the publications produced during the development of this research.

1- R. Al-Nuaimi and A.Al-Yasiri, “ENERGY EFFICIENT ROUTING IN WSN BASED ON VIRTUALIZATION”, College Dean’s Annual Research Showcase Event, University Of Salford, UK, 2014.

2- R. Al-Nuaimi and A.Al-Yasiri, “A NEW ENERGY-EFFICIENT CLUSTERING ALGORITHM FOR WIRELESS SENSOR NETWORKS BASED ON NETWORK FUNCTION VIRTUALISATION (NFV) AND THE LEACH ROUTING PROTOCOL”, College Dean’s Annual Research Showcase Event, University Of Salford, UK, 2015.

3- R. Al-Nuaimi and A.Al-Yasiri, “A NEW ENERGY-EFFICIENT CLUSTERING PROTOCOL FOR WIRELESS SENSOR NETWORKS BASED ON NETWORK FUNCTION VIRTUALISATION (NFV)”, The 6th International Conference on Information Communication and Management(ICICM 2016), IEEE Conference, UK, 2016.

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APPENDIXES

Appendix A (PDUs)

1- Type of Packet (ToP)

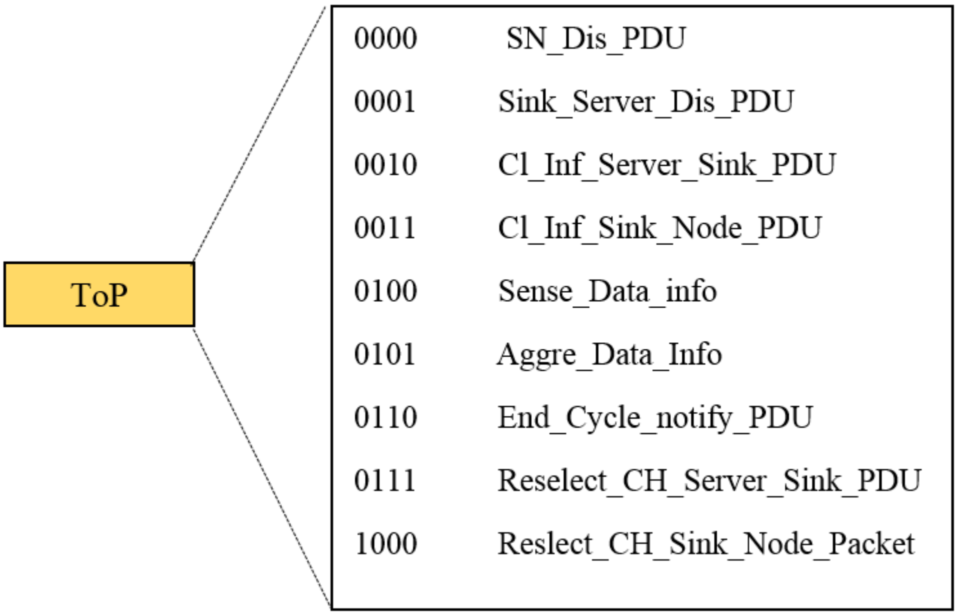


Figure (A-1) Type of Packet (ToP)

2- General Packet Format

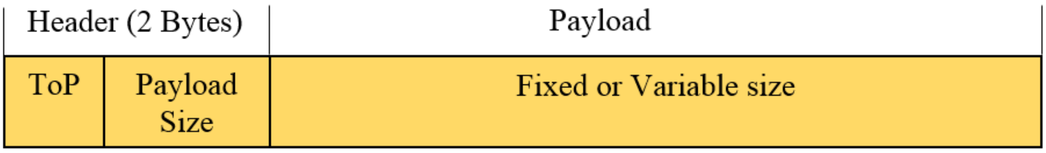


Figure (A-2) General Packet Format

Where **ToP** as is Figure (A-1)

Payload Size represents the total length of the payload which can be fixed or variable depends on packet type.

3- Node Discovery Packet (SN_Dis_PDU)

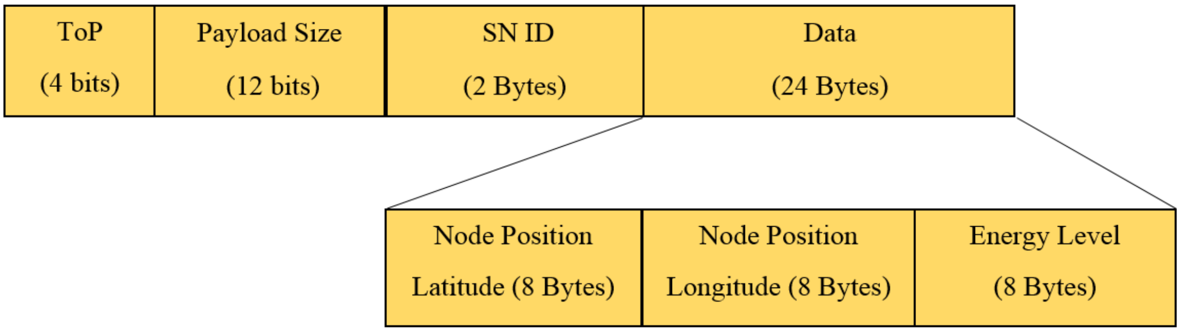


Figure (A-3) Node Discovery Packet (SN_Dis_PDU)

Where **ToP** as is Figure (A-1)

Payload Size represents the total length of the payload which is (26 Byte)

SN ID represents the unique identification for the sender node

Node Latitude and Longitude (X,Y) represents the node location in the sensing environment

Energy Level represents the current energy level of the node

4- Sink to Server Discovery Packet (Sink_Server_Dis_PDU)

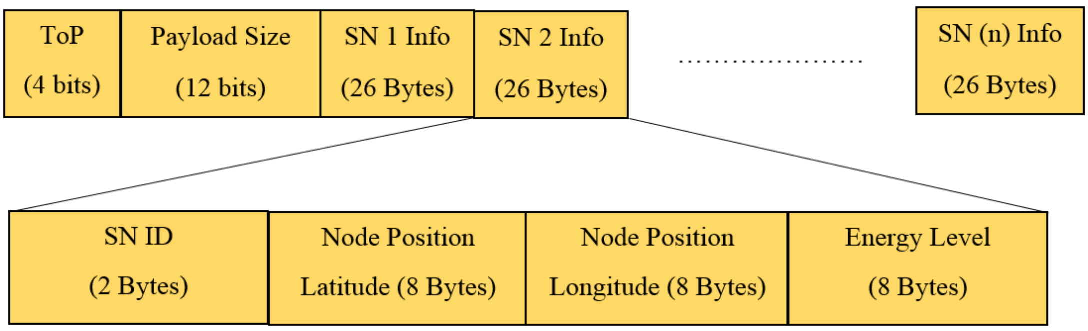


Figure (A-4) Sink_Server_Discovery Packet (Sink_Server_Dis_PDU)

Where **ToP** as is Figure (A-1)

Payload Size represents the total length of the payload which is variable and depends on number of SN_Info in the packet

SN ID represents the unique identification for the sensor node

Node Latitude and Longitude (X, Y) represents the node location in the sensing environment

Energy Level represents the current energy level of the node

5- Server to Sink Cluster Information Packet (Cl_Inf_Server_sink_PDU)

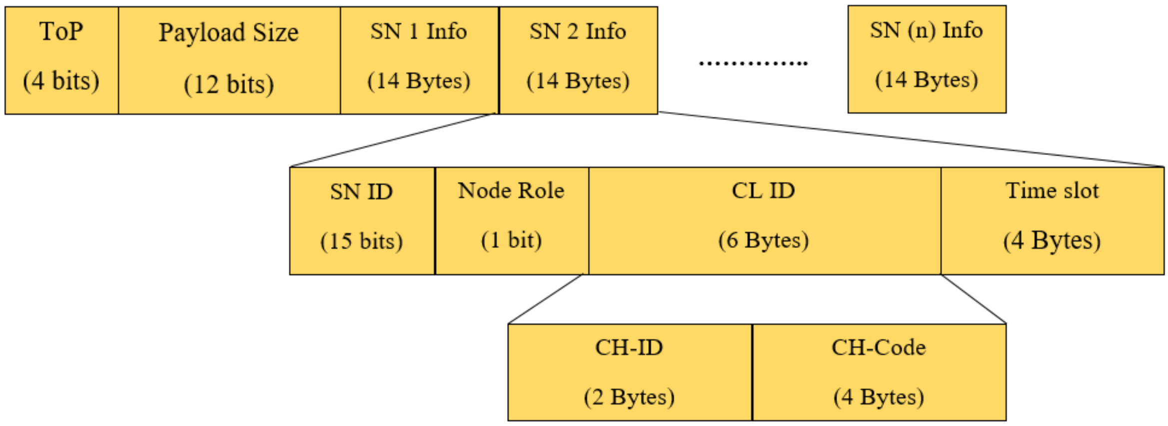


Figure (A-5) Server to Sink Cluster Information Packet (Cl_Inf_Server_sink_PDU)

Where **ToP** as is Figure (A-1)

Payload Size is the total length of the payload which is variable and depends on number of SN_Info in the packet

SN ID represents the unique identification for receiver node.

Node role represents the node mode which is either CH or CM. in this case, if role code is (1), its means that the node in CH mode and will take its time slot, otherwise, if the code is (0) this mean that the node is in CM mode and will take its CH ID and its time slot.

CL ID contained two field, CH-ID that represent the unique CH identification, and CH-Code, which is the unique cluster code used by cluster members and CH in data transmission.

6- Sink to Node Cluster Information Packet (Cl_Inf_Sink_Node_PDU)

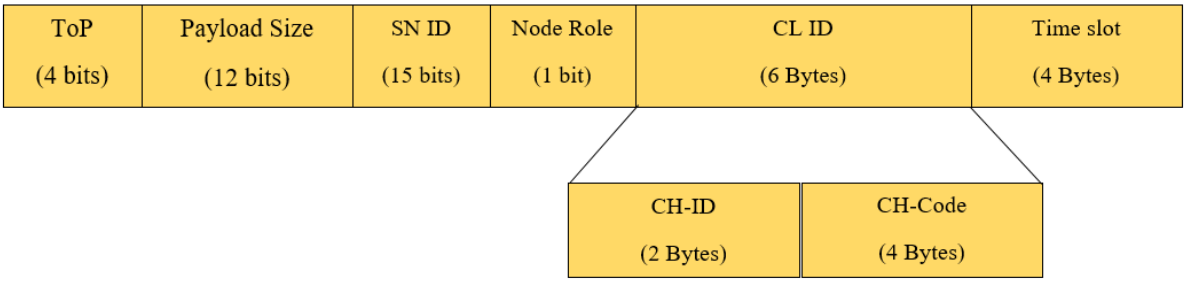


Figure (A-6) Sink to Node Cluster Information Packet (Cl_Inf_Sink_Node_PDU)

Where **ToP** as is Figure (A-1)

Payload Size is the total length of the payload which is 14 Bytes

SN ID represents the unique identification for receiver node.

Node role represents the node mode which is either CH or CM. in this case, if role code is (1), its means that the node in CH mode and will take its time slot, otherwise, if the code is (0) this mean that the node is in CM mode and will take its CH ID and its time slot.

CL ID contained two field, CH-ID that represent the unique CH identification, and Cl-Code, which is the unique cluster code used by cluster members and CH in data transmission.

Time Slot is a node’s transmission time slot

7- Sensed Data Info

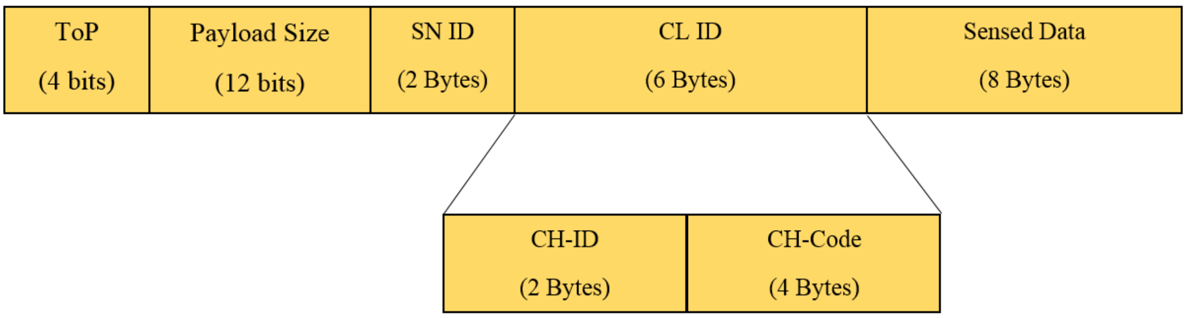


Figure (A-7) Sensed Data Info (Sense_Data_Info)

Where **ToP** as is Figure (A-1)

Payload Size is the total length of the payload which is 16 Bytes

Node ID represents the unique identification for sender node.

CL ID contained two field, CH-ID that represent the unique CH identification for the sender node, and CH-Code, which is the unique cluster code used by cluster members and CH in data transmission.

Sensed Data is the actual sensed data

8- Aggregation Data Info

ToP (4 bits)	Payload Size (12 bits)	CH-ID (2 Bytes)	CH-Code (4 Bytes)	Aggregated Data (8 Bytes)

Figure (A-8) Aggregated Data Packet (Agg_Data_Info)

Where **ToP** as is Figure (A-1)

Payload Size is the total length of the payload which is 14 Bytes

CH-ID that represent the unique CH identification for sender node.

CH-Code which is the unique cluster head code used by cluster head in sending the aggregated data to the sink

Aggregated Data is the aggregated sensed data

9- End Cycle Notification Packet (End_Cycle_notify_PDU)

ToP (4 bits)	Payload Size (12 bits)	Cycle ID (2 Bytes)

Figure (A-9) End Cycle Notification Packet (End_Cycle_notify_PDU)

Where **ToP** as is Figure (A-1)

Payload Size is the total length of the payload which is 2 Bytes

Cycle ID is current cycle number

10- Server to Sink Cluster Head re-selection Packet (Reslect_CH_Server_Sink_Packet)

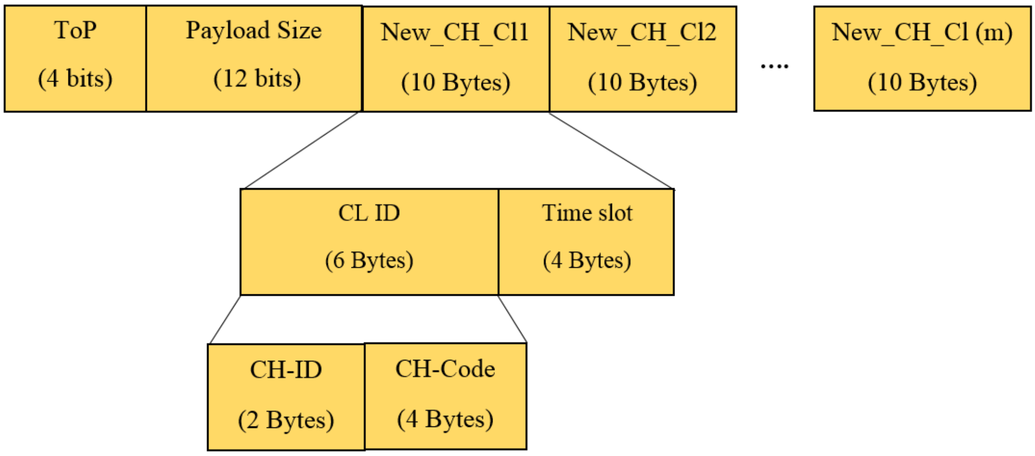


Figure (A-10) Cluster Head re-selection Packet (Reslect_CH_Server_Sink_Packet)

Where **ToP** as is Figure (A-1)

Payload Size (S) is the variable size that depends number of new cluster heads in the packet

CL ID contained two field, new CH-ID that represent the unique identification for new CH, and new CH-Code, which is the unique cluster code used by cluster members and CH in data transmission.

Time Slot is a node's transmission time slot

11- Sink to Node Cluster Head re-selection Packet (Reselect_CH_Sink_Node_PDU)

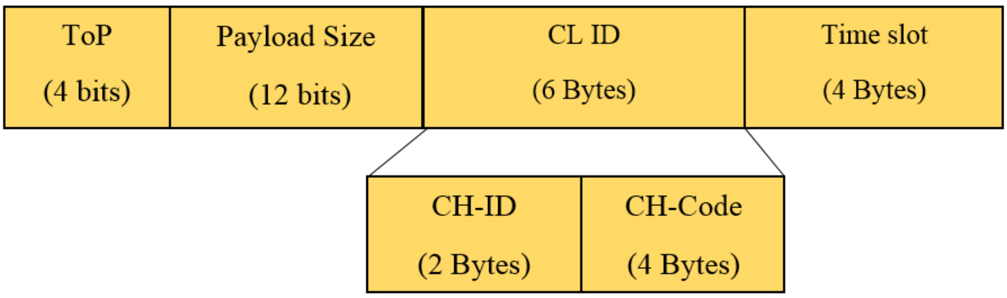


Figure (A-11) Cluster Head re-selection Packet (Reslect_CH_Sink_Node_Packet)

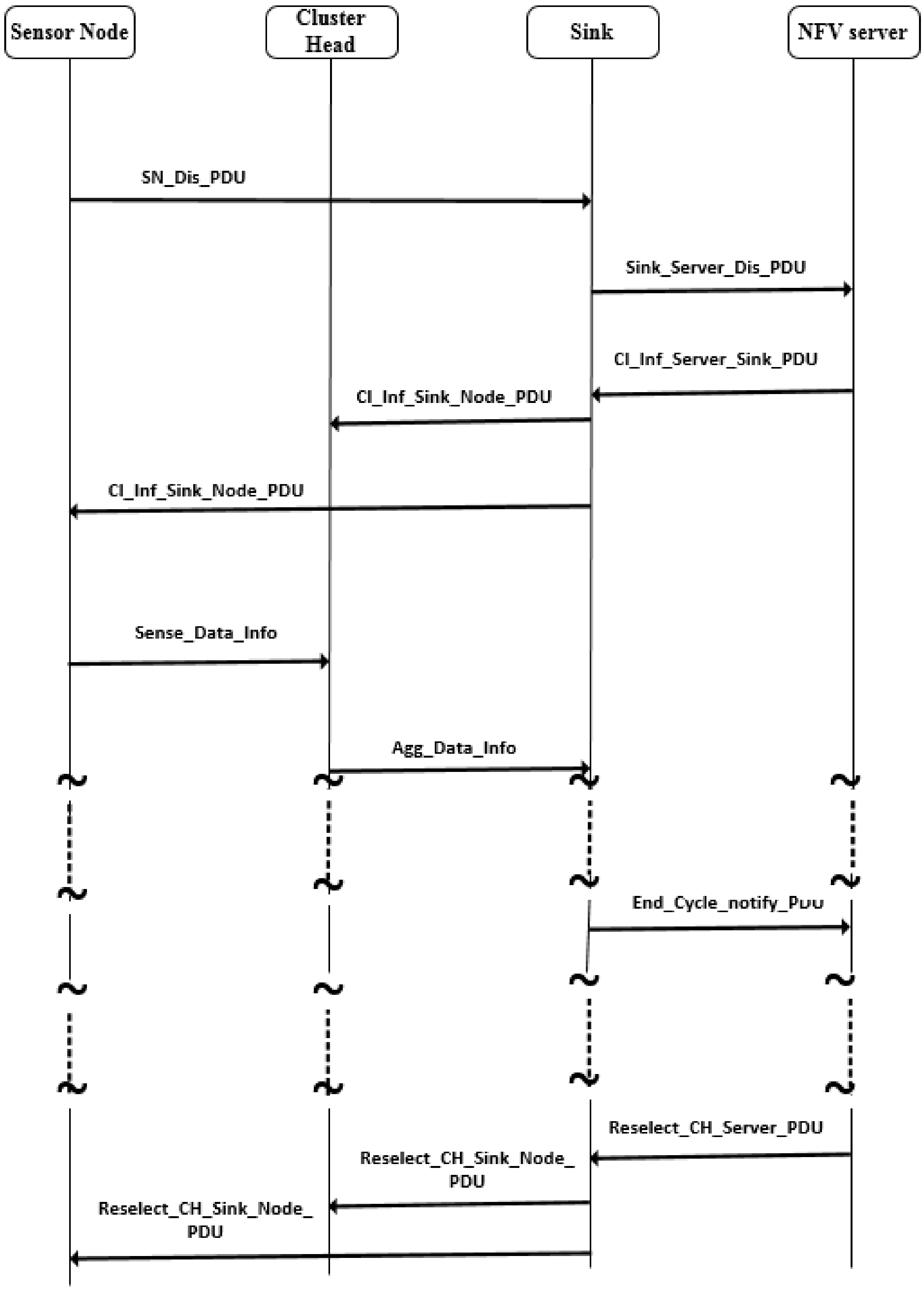
Where **ToP** as is Figure (A-1)

Payload Size (S) is the total length of the payload which is 10 Bytes

CL ID contained two field, new CH-ID that represent the unique identification for the new CH, and new CH-Code, which is the unique cluster code used by cluster members and CH in data transmission.

Time Slot is a node's transmission time slot

Appendix B (Protocol Diagram)



Appendix C
Virtualised Clustering Routing (VCR) Protocol Flow Chart

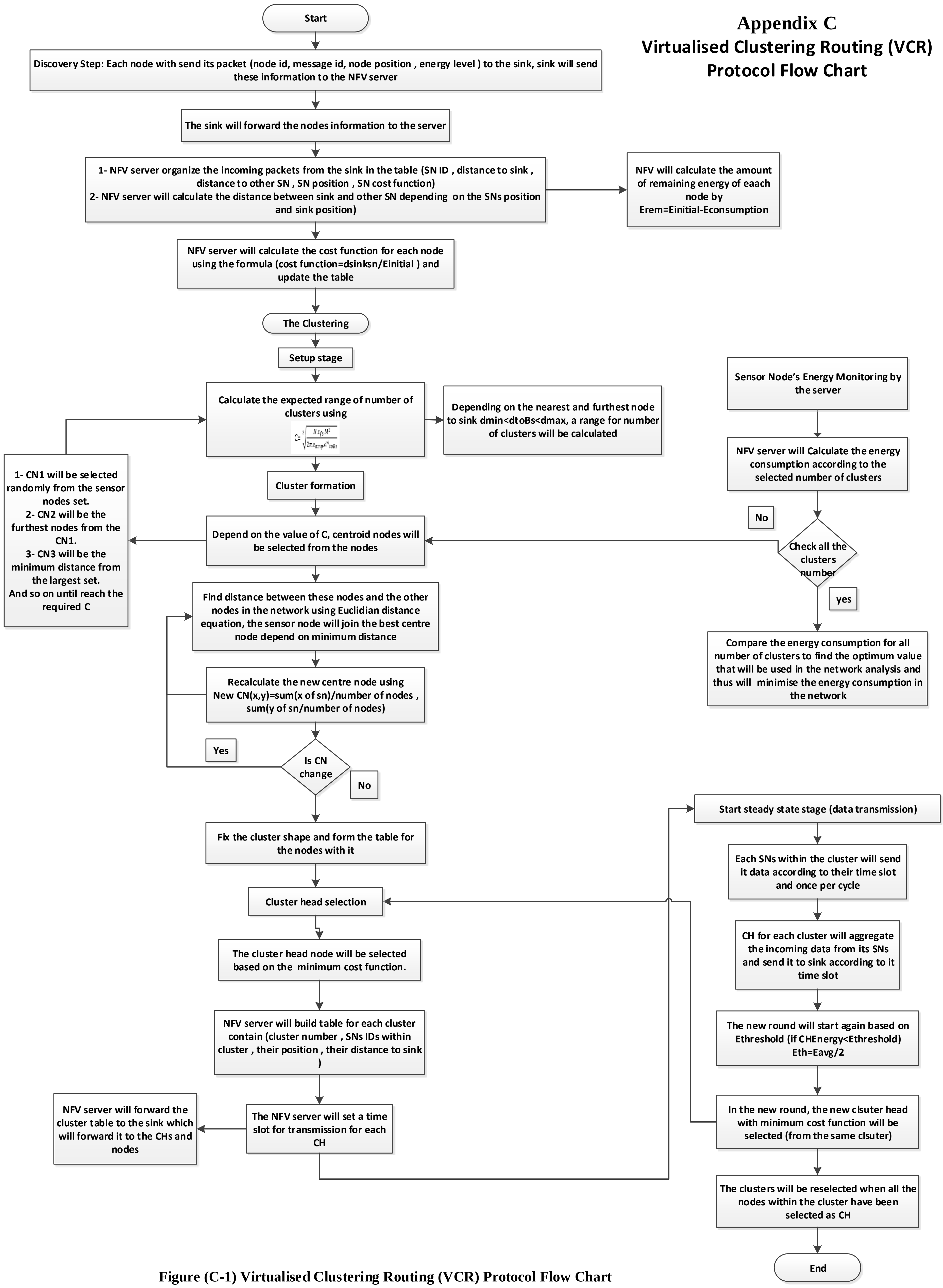


Figure (C-1) Virtualised Clustering Routing (VCR) Protocol Flow Chart

Appendix D/ Network Topologies

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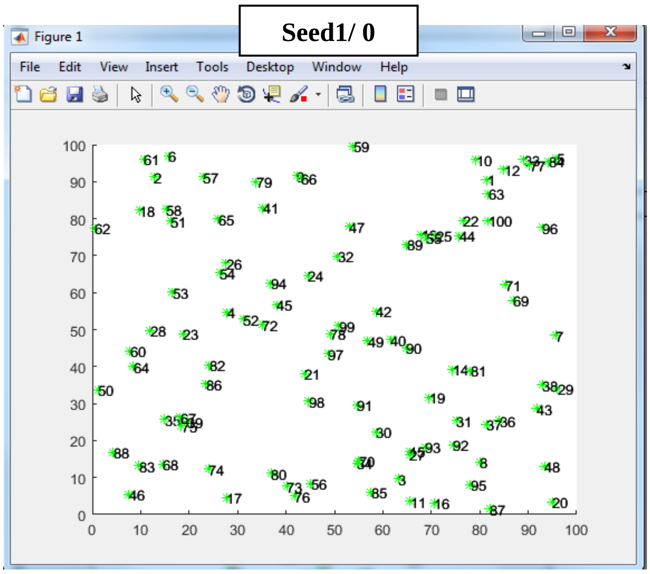

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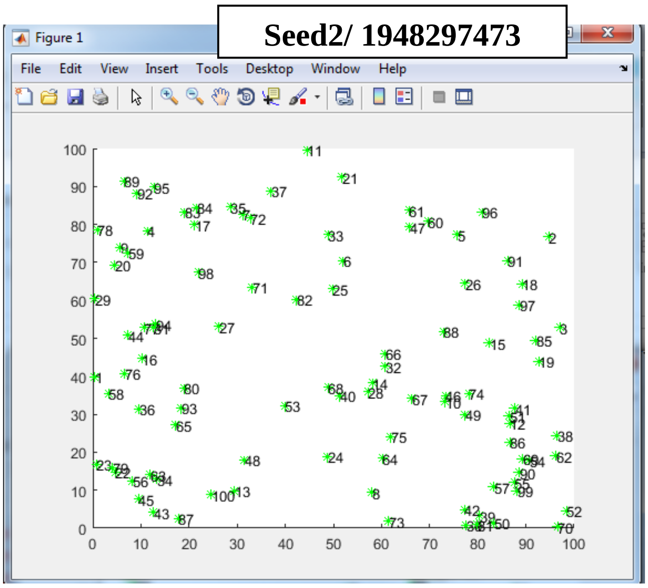

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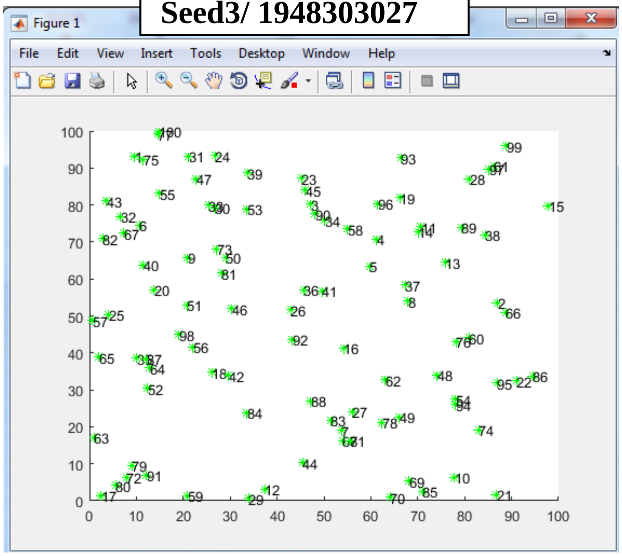

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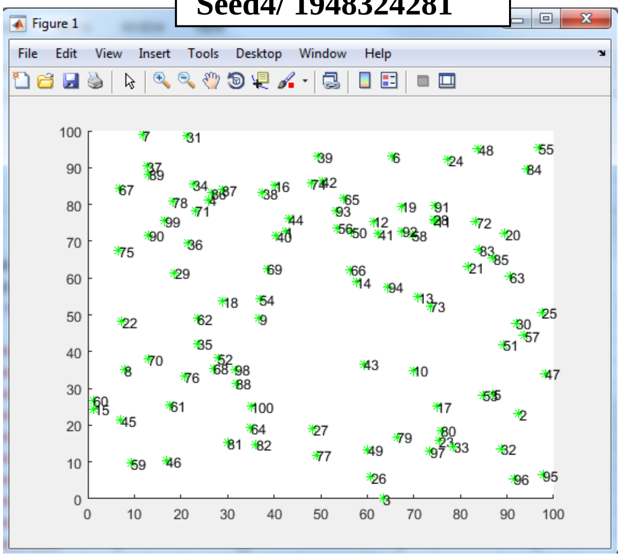

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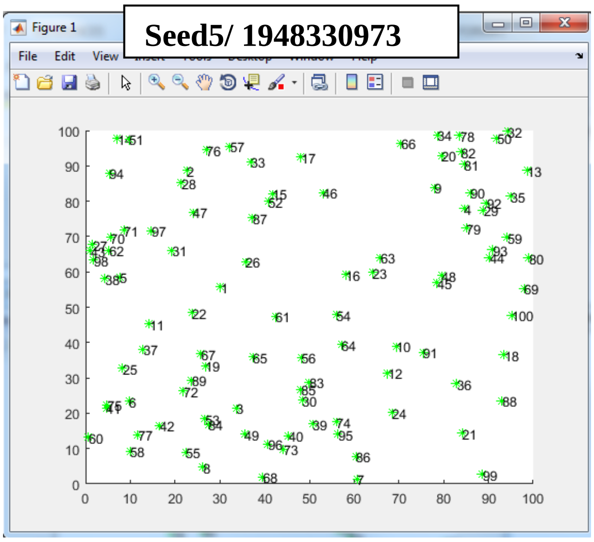

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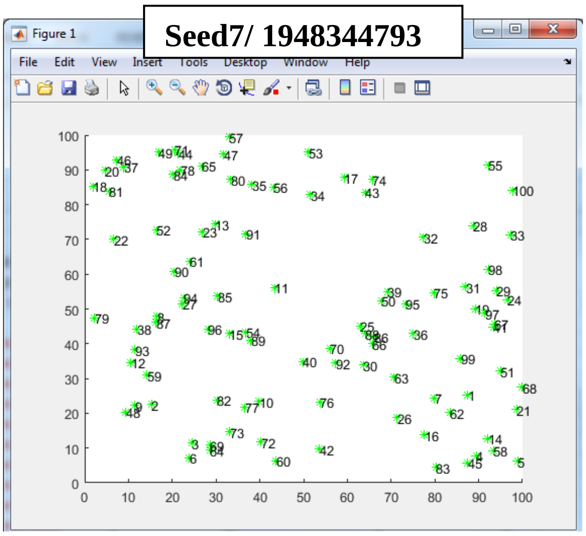

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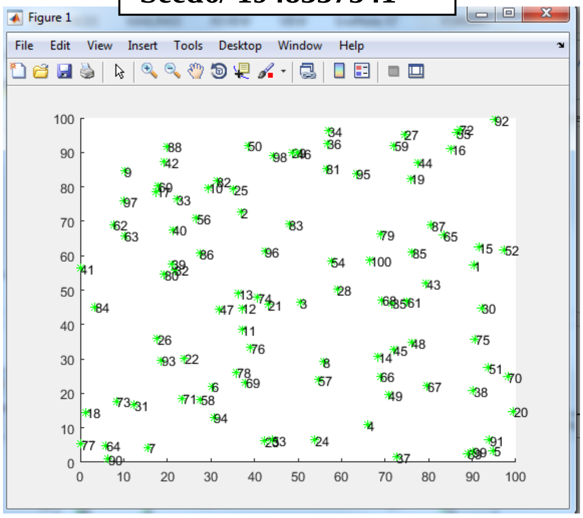

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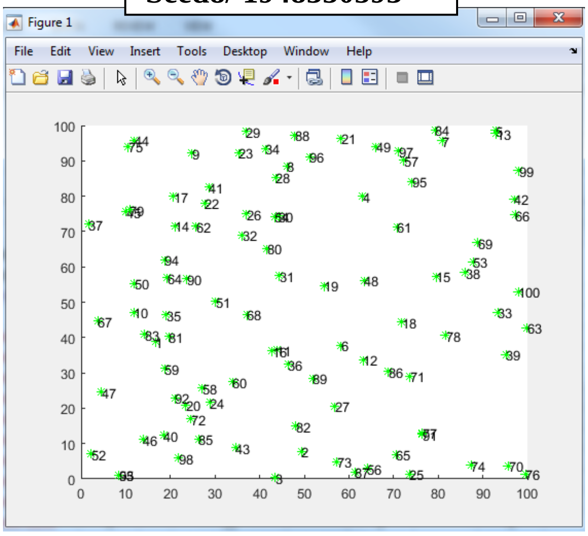
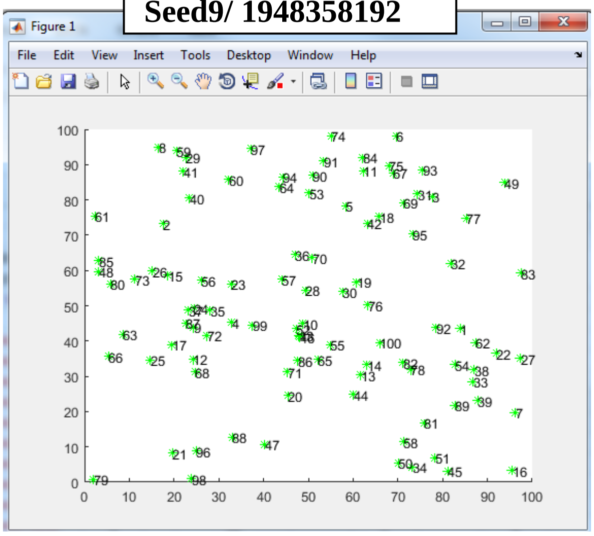


Seed9/ 1948358192



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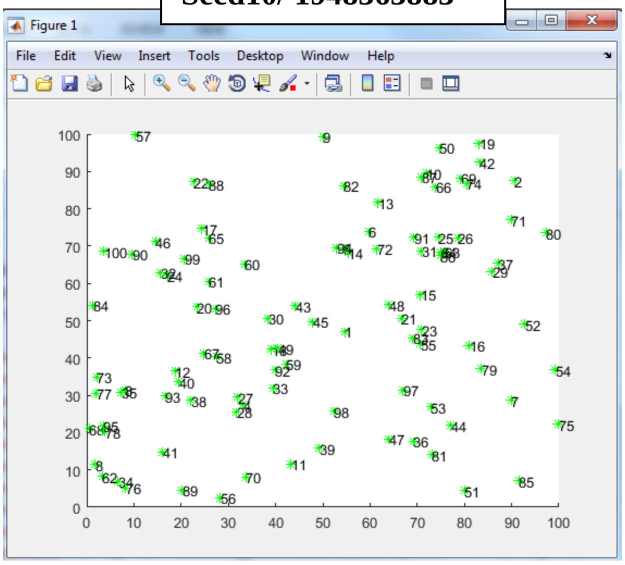
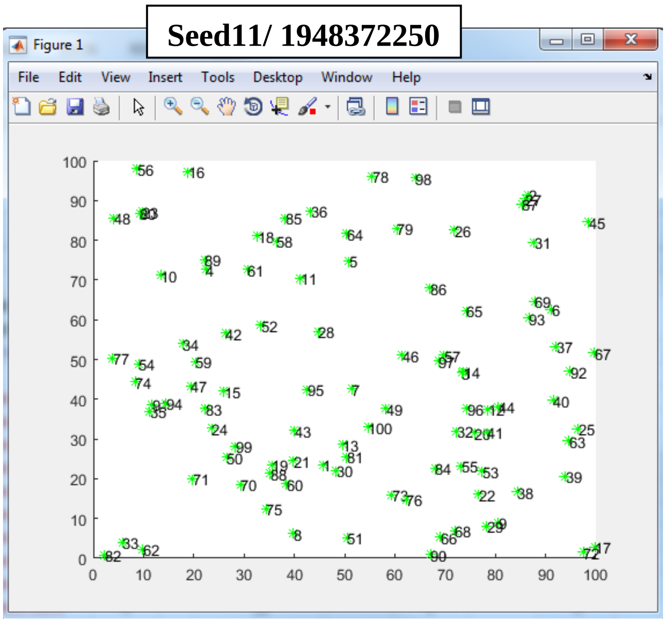
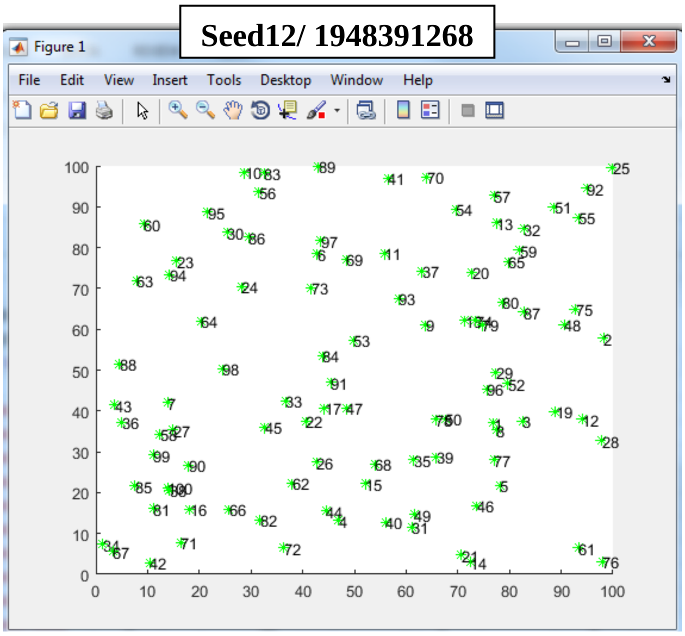
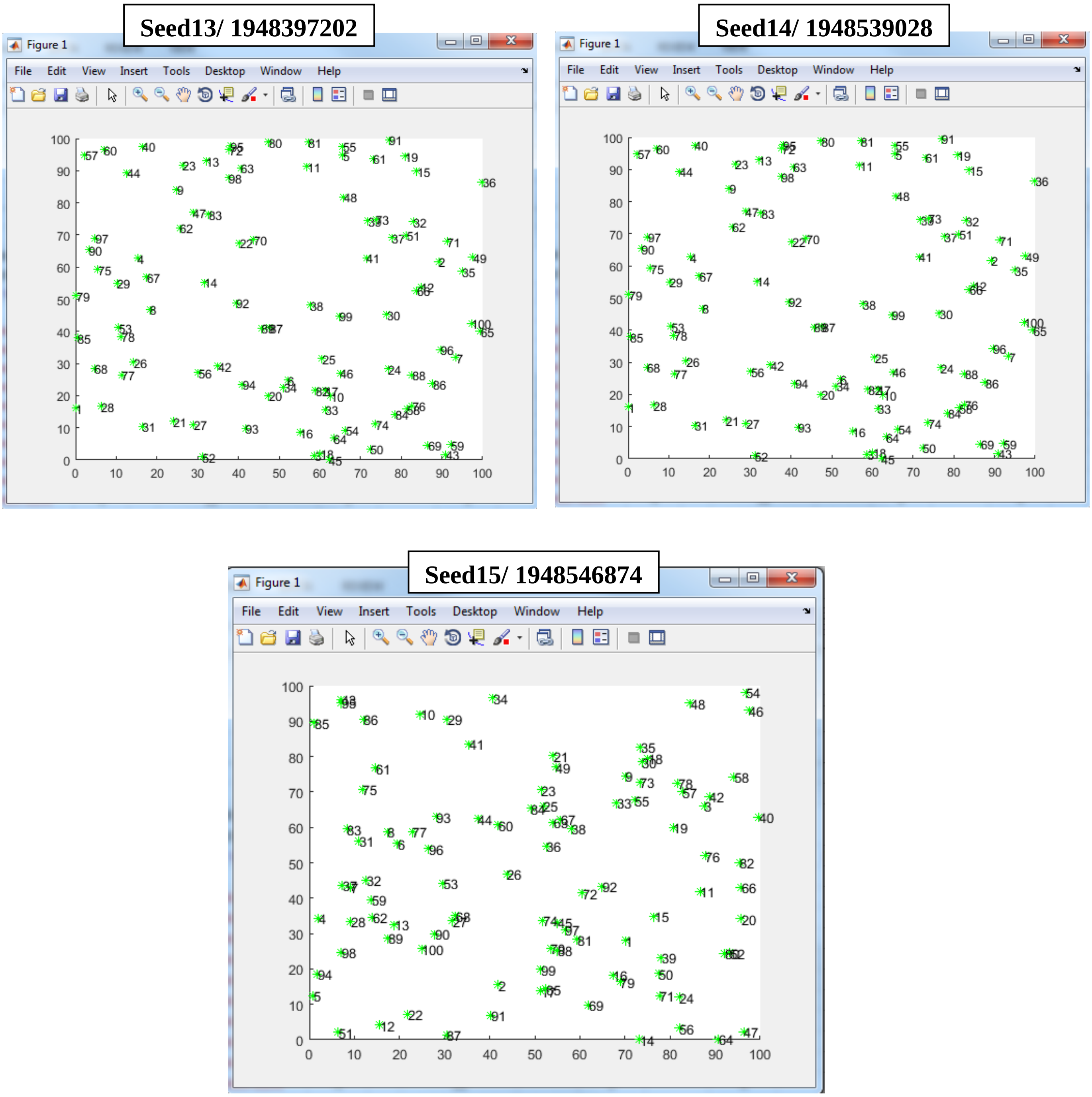


Seed11/ 1948372250



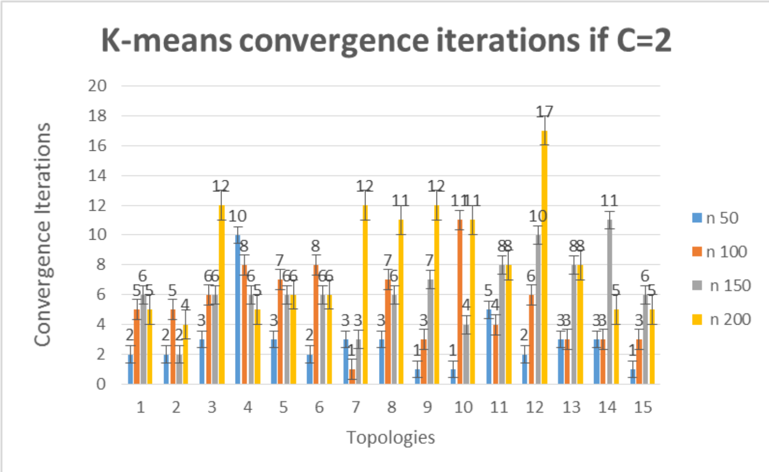
Seed12/ 1948391268



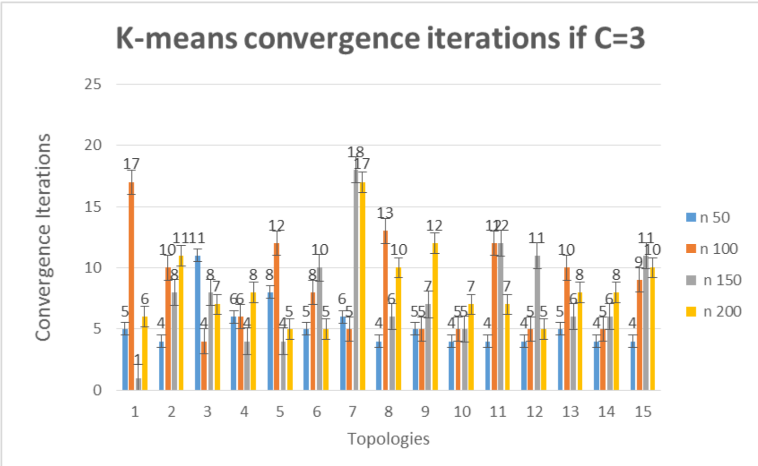


Figures (D-1) Network Topologies with various seed values

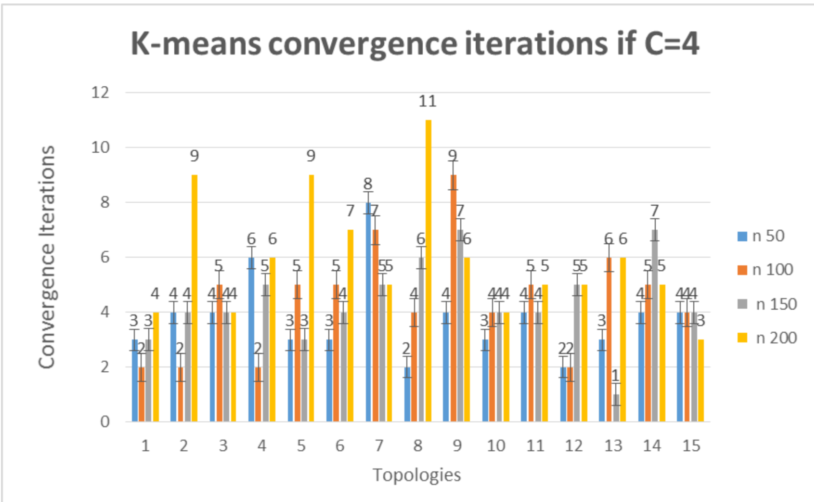
Appendix E (K-means convergence iterations for different topologies, nodes density and number of clusters)



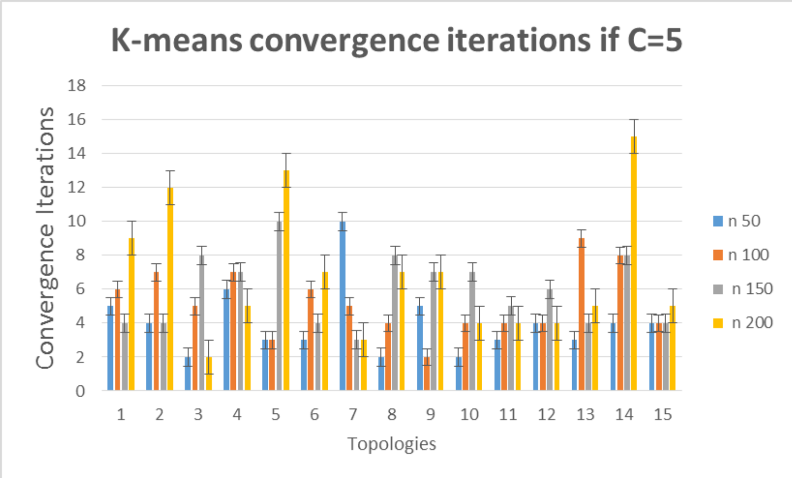
Figures (E-1) K-means convergence with two clusters



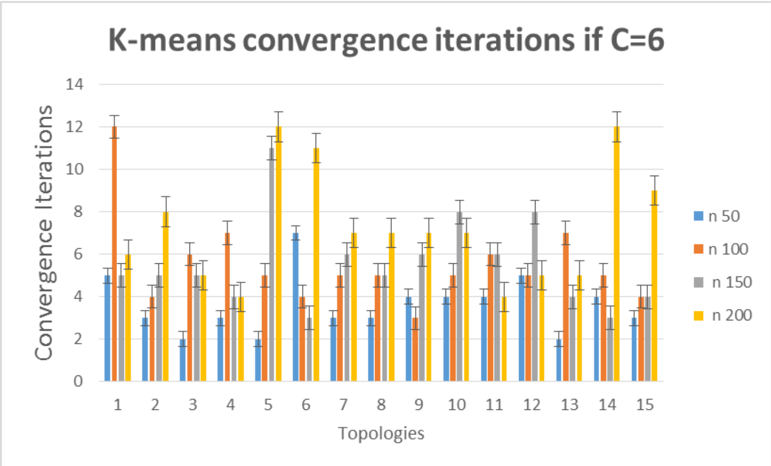
Figures (E-2) K-means convergence with three clusters



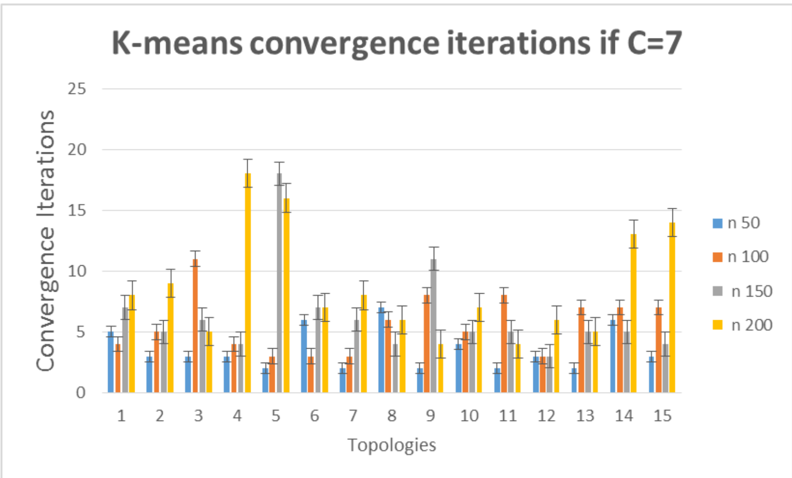
Figures (E-3) K-means convergence with four clusters



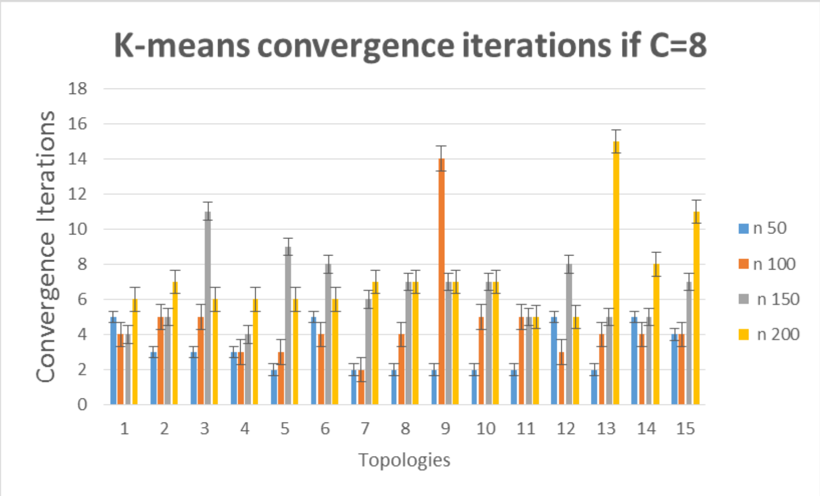
Figures (E-4) K-means convergence with five clusters



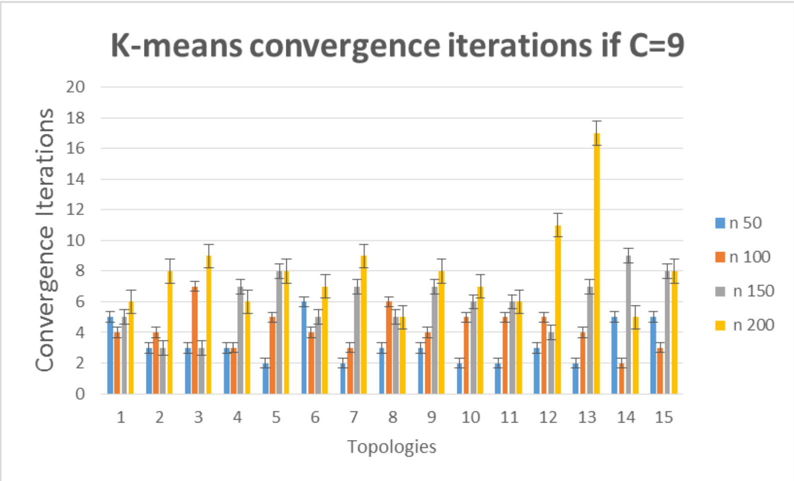
Figures (E-5) K-means convergence with six clusters



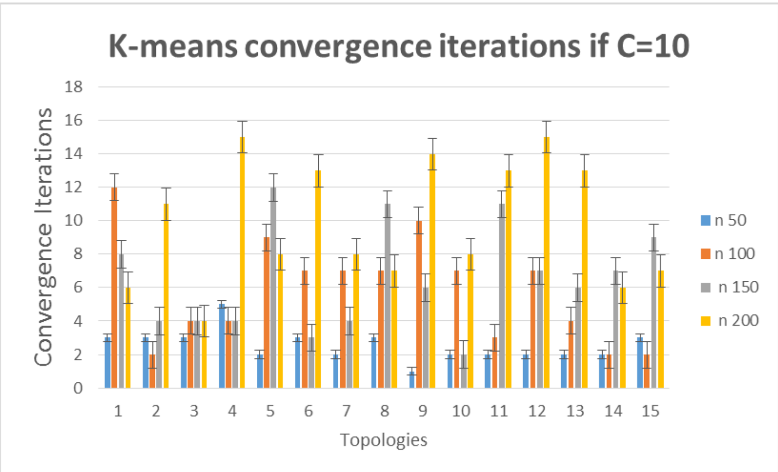
Figures (E-6) K-means convergence with seven clusters



Figures (E-7) K-means convergence with eight clusters



Figures (E-8) K-means convergence with nine clusters



Figures (E-9) K-means convergence with ten clusters